

Field Evaluation of Chemical Protective Suits



**Federal Emergency Management Agency
United States Fire Administration**



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**FIELD EVALUATION
OF
CHEMICAL PROTECTIVE SUITS**

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**FINAL REPORT, TASK 1
United States Fire Administration
Federal Emergency Management Agency
CONTRACT EMW-88-R-2755**

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PREFACE

This study was funded by the U.S. Fire Administration, Federal Emergency Management Agency (FEMA) under contract EMW-88-R-2755. This contract was monitored by Mr. Bob McCarthy of the U.S. Fire Administration, Emmitsburg, MD. My special thanks to Fire Chiefs Jan Dunbar and Dale Templeton, Sacramento Fire Department CA; Mr. Greg Nail, Prince Georges County Fire Department, MD; Chief Steve Stormont, Phoenix Fire Department, AZ; and, Lt. Wayne Yoder, DelRay Beach Fire Department., FL for their assistance in successfully conducting these tests at the various field test sites. And foremost, I wish to thank all the fire fighters and the personnel of the Sacramento, CA; Prince Georges County, MD; Phoenix, AZ; and DelRay Beach, FL Fire Departments who participated in this study and made it all possible. The fire fighters participating in this study were:

SACREMENTO, CA

Craig Barmsby
Merlin Glass
Karen Parker
Steven Siligo
Edward Vasques

PRINCE GEORGES COUNTY, MD

Phillip Baker
Janet Fisher
John Fletcher
Thomas Stanton
John Trevathan

PHOENIX, AZ

Terry Demarr
Jim Russell
John Valenzuela
Michael Walters
Nathan White

DELRAY BEACH., FL

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Roberto Betancourt
Peter Carafaro
John Hanson
Michael McCleary

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ABSTRACT

Five experienced hazardous material fire fighters participated in field tests at each of four cities to evaluate the Challenge chemical protective clothing with one or two exhaust valves. The climatic conditions at these test sites were comfort (61°F), cold (35°F), hot/dry (99°F) and hot/wet (92°F). The work tasks prescribed in the ASTM F-1154 were conducted at each test site to evaluate the suit construction and human factors associated with wearing this clothing. The average work duration was 14 minutes to complete these tasks. Each fire fighter performed these work tasks wearing either the Challenge protective clothing with 1 or 2 exhaust valves or their station uniform without an SCBA to provide control values. The Challenge suits were worn with SCBA. Rectal temperatures (TR), heart rates (HR), nude and clothed weights and climatic parameters were recorded before and after each test. Test results showed average TR, HR and sweat losses increased to 100.4°F, 152 beats/min and 0.60 lbs respectively during the hot/wet exposures. The wet bulb globe temperature (WBGT) levels for the hot/wet conditions were equal to the NIOSH recommended limiting criteria. Physiologic parameters measured during comfort and cold conditions were similar. The design of the protective clothing resulted in upward and downward vision impairment, difficulty in performing overhead work and climbing ladders. The fire fighters preferred the two exhaust valves in the suit over the single valve because of increased venting during bending movements. The ASTM F-1154 testing procedures were not strenuous enough to adequately evaluate this clothing.

INTRODUCTION

During the past twenty years, the fire service has been called upon with increasing frequency to respond to toxic chemical spills and to the fires associated with them. These incidents have become more critical over the past ten years as public awareness to the potential seriousness of the problem has increased. This responsibility for fire service personnel has thrust them into a new area that requires different protective clothing than the standard "turnout" clothing. It has also made necessary new procedures for handling these incidents. Although federal and professional guidelines for handling hazardous material (HAZMAT) incidents are being developed, few studies have addressed protective clothing requirements (Schwope et al 1983; Unknown author, 1984; 1985). The obvious problem of chemical permeation through protective clothing was the first to be addressed. Subsequently, Nol. (1984) and others developed classes of HAZMAT incidents that require different levels of clothing protection. However, until recently, the physiologic impact of wearing the impermeable HAZMAT clothing has not been addressed by the fire service (Veghte, and Annis, 1988a). However, other scientists have studied the physiologic response of exercising people exposed to temperature extremes dressed in impermeable clothing. The results of some of these studies are described below

Impermeable clothing is defined as clothing which prevents transfer of water and water vapor. Because the impermeable material blocks water vapor transfer, in hot weather evaporative cooling from body sweat is reduced. Since evaporative cooling is the major physiological protection against overheating, impermeable clothing can present a serious limitation in high temperatures. In an early study, Craig (1950) exposed exercising men who were completely covered in an impermeable suit to a temperature of 80°F. These subjects had a physiological tolerance limit of approximately 30 minutes. In another study, Darling, et al (1943) studied a large number of men marching at three miles per hour while clothed in decontamination suits. The air temperatures ranged from 70° to 85°F. The tolerance time at 70°F was approximately 100 minutes. Their tolerance time steadily decreased as the temperature increased until at 85°F the tolerance time was only 25 minutes. Griffin, et al (1944) found that subjects dressed in heavy insulation (4 clo) and an exposure suit collapsed in 90 minutes at 90°F. Without the exposure suit, collapse was delayed until 150 minutes. In another series of tests using heavy clothing (3.3 clo), Hall (1952) found that putting a light impermeable exposure suit over the clothing doubled the sweating rate and caused high skin temperatures. In a report by Robinson, et al (1945), a comparison was made among several types of exposure suits, vapor permeable and impermeable. Test temperatures were 80°F and 100°F with varying humidities and the men were either exercising constantly or intermittently. Discomfort was produced by all the suits with the criteria being a high skin temperature (95°F or above). Unusual moisture retention in the clothing was due to the profuse sweating of the subjects. In one of the few relevant field studies, Smolander et al (1985), determined the heart rate (HR), rectal temperature (TR) and metabolic levels of fire fighters working for 37 min in a gas protective suit during cold conditions (36°F). Their findings showed a HR increase up to 148 beats/min, TR rise of 1.5°F and sweat loss of 0.66 lbs.

In a report by White and Hodous (1987), subjects wearing chemical protective clothing exercised on a treadmill at various work levels in a thermally neutral environment (dry bulb 73°F, wet bulb 63°F). Their results showed that even at low work intensity (4 METS) tolerance time was limited to 73 mins. Tolerance time was defined as 90% of maximal HR, a TR of 102.2°F or the subject's inability to proceed. At high work levels (7.7 METS), tolerance time working in this clothing was 13 mins. One MET is defined as a metabolic rate of 50 Calm²/hr which is the ordinary metabolism of a person seated performing a sedentary task. Eley (1987) conducted a study with exercising subjects wearing the Challenge fully encapsulated HAZMAT suit

and found that at ambient temperatures of 89°F, HRs rose 40 beats/min over control values. During the forty min test exposure, the body core temperatures rose as high as 100.6°F.

In a recent study, five experienced hazardous material (HAZMAT) fire fighters participated in field tests at each of four cities to evaluate three HAZMAT protective ensembles (Veghte and Annis, 1988a). The climatic conditions for these field studies were hot/dry (102° to 108°F), hot/wet (86° to 93°F), comfortable (70° to 81°F) and cold (42° to 45°F). Each fire fighter served as his own control and wore a specific HAZMAT protective ensemble once a day for three days. Each test involved an operationally relevant 45 min work session during a total test duration of 55 mins. Rectal temperatures (TR), heart rates (HR), blood pressures, respiration rates, clothed weights and climatic parameters were recorded before and after each test. Test results show average TR, HR and sweat losses increased to 101.4°F, 208 beats/min and 3.5 lbs respectively during the hot/dry and hot/wet exposures. The wet bulb globe temperature (WBGT) levels for the hot/dry conditions exceeded the NIOSH recommended limiting criteria and was marginal for the hot/wet tests. Physiologic parameters measured during comfortable and cold conditions were similar to each other and lower than those measured during the hot/dry or hot/wet conditions. Differences in suit design were clearly reflected in the measured physiologic parameters and the effort required to perform work. Suggested suit modifications were discussed to reduce clothing encumbrance and enhance work efficiency.

With the tolerance time variously defined in the lower ambient temperature ranges (70° to 90°F) and nonexistent at the higher temperatures (100° to 160°F), it is important to conduct field studies with HAZMAT clothing to quantify the physiologic responses of the fire fighter. The question then arises as to how this physiologic data can be formatted in a useful way for the fire service. Most fire departments do not have the means or the time to measure physiologic parameters other than heart rates. Therefore in a recent paper, the WBGT measurement of the environmental conditions was used as a means of providing a connecting link to heart rate, rectal temperature and sweat loss, (Veghte, 1988b). Additional support in selecting WBGT's as a useful index is that NIOSH uses this parameter to formulate work/rest times for hot environments (Unknown author, 1986). Thus, knowing the WBGT at the fire scene, the fire scene commander can get a rough idea of the physiological response of the fire fighters to the work load and environmental conditions. Also these charts provide a preliminary data base that can be added to by future field studies. This information can then be used to assess the degree of physiologic strain imposed on the fire fighter by his clothing and his work.

The evaluation of the government furnished chemical protective suits also requires an investigation of differences in wearer/suit performance as attributed to differences in exhaust valve configurations. Suit exhaust valves function to vent exhalation air from the wearer's breathing apparatus as this air accumulates inside the suit. In general, these valves are designed to exhaust air at a pressure slightly higher than ambient (0.1-3 inches water pressure gauge) thus maintaining a positive pressure within the suit. For the most part these valves are similar in construction to those used in respiratory protective equipment and are assumed to prevent backflow of air into the suit from the outside environment. Tests by Lawrence Livermore National Laboratory conducted for the U.S. Coast Guard and the United States Fire Administration have shown some leakage for representative suit exhaust valves. The significance of this valve leakage has not been determined. Additionally, the pressure at which the valve opens (known as the "cracking pressure") may have a significant impact on user freedom of movement. Stull (1987) described changes in the exhaust valves for the Coast Guard's Chemical Response suit due to overinflation within the garment. While some positive suit pressure is desired to reduce the likelihood of outside contamination entering through suit valves, positive pressures which are too high can limit the wearer's mobility and require more energy expenditure

for the wearer to perform the required tasks. The Challenge 5200 suits to be evaluated will contain either one or two exhaust valves.

Cold can also seriously impair a fire fighter's performance. Since fire fighters must operate effectively in all weather conditions, the effects of cold on the body's physiological responses is important. Periodic food intake maintains body temperature relatively constant at 37° to 37.5° C (98° -99.5°F). Clothing provides insulation that keeps this heat from escaping. The clothing's effectiveness depends upon its thickness and how it is worn. Research has shown that effective insulation is produced by layering. Several layers of lighter weight clothing provide more warmth than one layer of heavy clothing, because multi-layered clothing is able to trap more air between its layers. Cold temperatures can effect the stiffness of plastic or other synthetic materials which can then effect the amount of energy required to perform essential HAZMAT work. Wind greatly increases the convective heat transfer from exposed skin and, to a lesser extent, from clothing. The commonly referred to Wind Chill Index expresses equivalent temperatures with various wind speeds (Siple, 1945). It is extremely important to understand that these equivalent temperatures only apply to exposed skin.

In most HAZMAT situations, the only exposed skin surface is the area of face around the face mask in a level B suit. Fingers, ears, toes, and face are the most likely areas to become numb or to freeze. Normally, the feet are first to become cold and are the critical regions of the body to keep warm and dry. Hands, too, are very susceptible to cold. In general, serious deterioration in hand mobility and function occurs when the finger temperatures drop below 16°C (60°F) (Dusek, 1957). This loss in manual performance is very significant at skin temperatures below 10°C (50°F). Below 4°C (40°F), the fire fighter begins to completely lose his ability to feel and to perform tasks requiring fine movement. As skin temperatures fall below 19°C (65°F), the skin's superficial blood vessels constrict, and the flow of warm blood is reduced. If skin temperatures fall below 9°C (48°F) pain can develop. As skin temperatures approach 0°C (32°F), numbness is likely to occur. As the extremities become accustomed to the cold and skin temperatures approach freezing, the skin blood vessels adjust and open rhythmically (Lewis effect). Warm blood then flows to the cold areas, and frostbite is prevented.

The objectives of his study were 1) to measure the physiologic responses of fire fighters wearing HAZMAT Protective Ensemble during operationally relevant HAZMAT work conditions; 2) to determine the magnitude of the restrictive effects of the HAZMAT Protective Clothing Ensembles on body mobility through the use of anthropometric measurements procedures; and, 3) improvement in protection and design of future fire fighter's HAZMAT protective clothing and reduction in fatigue as a result of more functionally designed HAZMAT clothing.

METHODS

A total of twenty experienced fire service HAZMAT trained personnel in designated Fire Departments across the country participated in this study. These test volunteers were in good physical condition. Field tests were conducted with five fire fighters at four separate geographical locations. The cities that participated in this study were: Phoenix, AZ (hot/dry); DelRay Beach, FL (hot/wet); Sacramento, CA (comfortable); and, Prince Georges County, MD (cold). The climatic conditions for these four tests were cold (24-44° average 35°F), comfortable (50-71° average 61°F), hot/dry (96-104° average 99°F) and hot/wet (84-95° average 92°F).

Phase 1: Physiologic Evaluation: Each test subject wearing a specific HAZMAT protective ensemble or station uniform was tested once a day for three consecutive days. Each test had one complete work session which included all the tasks in procedures A and B. Each person served as their own control. Two different level A HAZMAT clothing ensembles were tested: the commercial, Challenge protective ensemble furnished by the U.S. Fire Administration with one or two exhaust valves.

The experimental procedure was to weigh the subject nude and instrument him/her with a rectal temperature (TR) probe inserted 10 cm into the rectum by the individual. Dressing was accomplished in a cool environment to preclude sweating before the test commenced. The totally clothed subject was then weighed. The subject then proceeded with the prescribed work task. TR and Heart Rate (HR) were recorded before and after each test. The ambient temperature (TA), ambient humidity (RH), globe temperature (GT) and wet bulb-globe temperatures (WBGT) and wind velocity (WV) were recorded. Data was logged on prepared sheets for each test.

Workloads: The individual work tasks was standardized as much as practical to eliminate experimental variables. Duration to complete all work tasks was approximately 14 minutes. A different clothing ensemble was worn on any given day. Figure 1 depicts the various tasks performed.

Table 1. ASTM F-1154 WORKLOADS PROCEDURES A AND B

Procedure A

1. Kneel on left knee, kneel on both knees, kneel on right knee, stand. Repeat exercise a total of three times.
Duck squat, pivot right, pivot left, stand. Repeat exercise a total of three times.
2. Stand erect. With arms at sides, bend body to left and return, bend body forward and return, bend body to right and return. Repeat exercise a total of three times.
4. Stand erect. Extend arms overhead, then bend elbows. Repeat exercise a total of three times.
5. Stand erect. Extend arms perpendicular to the sides of torso. Twist torso left and return, twist torso right and return. Repeat exercise a total of three times.
6. Stand erect. Reach arms across chest completely to opposite sides. Repeat exercise a total of three times.
7. Walk a distance of 100 yds (or walk in place for a minimum duration of 3 min).
8. Crawl on hands and knees a distance of 20 ft (or crawl in place for a minimum duration of 1 min).

Procedure B

9. Individually lift four hoses from the floor and place on a table. Return each box to floor.
10. Place a 55-gal drum on a handtruck and move 25 ft. Remove drum from handtruck. Replace drum on hand truck and move to original position. Remove drum from handtruck.
11. Uncoil and coil hose, disconnect and reconnect hose coupling.
12. Open overhead valve. Close overhead valve.
13. Remove and install bolt with wrench.
14. Remove and install screw with screwdriver.
15. Climb up to fifth rung of ladder.
16. Remove protective ensemble.

Clothing: Each fire fighter was dressed in his/her usual undergarments, station uniform and street shoes. In addition, they wore a HAZMAT protective ensemble, a hard hat and self contained breathing apparatus (SCBA) with the straps cinched down. Each suit was pressure tested before and after each work session. The average weight of the clothing and equipment was approximately 50 lbs Two inside HAZMAT garment surface temperatures were measured. One suit temperature site was immediately above the visor while the second was immediately below the visor. Suit temperatures were measured with a YSI Model 46 TU telethermometer, using series 400 thermistor probes. All clothing met departmental requirements and all Fire Department safety precautions normally taken were observed. The station uniform served as control in this study and was worn without an SCBA.

Instrumentation

- 1) A precise portable balance (FWC Model IV) capable of measuring up to 300 pounds with an accuracy of +9 grams.
- 2) A model 46 Yellow Springs Telethomometer recorded rectal temperatures. Five YSI rectal probes are required (Model 401).
- 3) HR was taken with a NASA 1,2,3 Heart Rate Monitor.
- 4) Environmental temperatures were measured with a portable RSS-211 WIBGET.

Volunteer: All volunteers were trained, experienced HAZMAT fire service personnel. They had sufficient experience in the use of the department's HAZMAT ensembles so they could compare the prototype clothing with that normally worn.

Questionnaires. Data Collection and Analysis: The contract test monitors were responsible to ensure proper logging of all data on the appropriate forms. The appropriate data analysis was accomplished by these test monitors. A post test questionnaire was filled out by each fire fighter at the end of each condition. The purpose of this questionnaire was to obtain subjective comments and observations as to the suit design, fit and encumbrance while performing the work. The fatigue questionnaire attempted to quantify the work involved. A code number was assigned each subject during data analyses. Collation and final statistical treatment of all the data was accomplished at a later time by the contractor using an appropriate Macintosh software package.

Fatigue Assessment: A subjective rating system known as the School of Aerospace Medicine (USAF/SAM) Fatigue Scale was used to assess the level of perceived fatigue experienced by the professional fire fighters after each test. This scale was originally developed for applied research by the U.S. Air Force and is currently being used by

several international organizations for the study of stressor effects (Pearson and Byars, 1956). As shown in Table 2, the SAM fatigue scale consists of ten statements. Each statement described a condition which the rater evaluates as “better than”, “same as” or “worse than” his or her own present status. An individual’s fatigue score is quantified by weighting the sums of the check marks in each rating column by 0, 1, and 2 respectively. Scores can range from 0 (low fatigue) to 20 (high fatigue). The purpose of employing the SAM scale in the present study was to compare the effects of different protective clothing ensembles on the fatigue levels reported by the fire fighters.

TABLE 2.
SUBJECTIVE FATIGUE SCALE

NAME		DATE/TIME	
INSTRUCTIONS: Make one check mark for each of the ten items. Think carefully how you fell right now			
STATEMENT	BETTER THAN	SAME AS	WORSE THAN
1. Very lively			
2. Extremely Tired			
3. Quite fresh			
4. Slightly pooped			
5. Extremely pooped			
6. Somewhat fresh			
7. Petered out			
8. Very refreshed			
9. Fairly well pooped			
10. Ready to drop			

Safety Precautions: All appropriate Fire Departmental, state and federal safety procedures were adhered to throughout this training exercise and took precedence over this study. A paramedic was available at the test site throughout the study. Physiologic tolerance criteria for this study was a TR of 102.2°F or a HR of 180 for 3 minutes. Termination of any tests was mandatory upon the request of: 1) the fire fighter; 2) the fire fighter’s site supervisor; or, 3) upon the discretion of the test monitor based on subjective or the above physiologic criteria. For each test a paramedic team stood by with appropriate equipment in the event of a medical emergency.

Prior Consent: This training test protocol had the approval not only of the fire fighters but also his/her supervisor and, if deemed appropriate, by the department’s medical advisor.

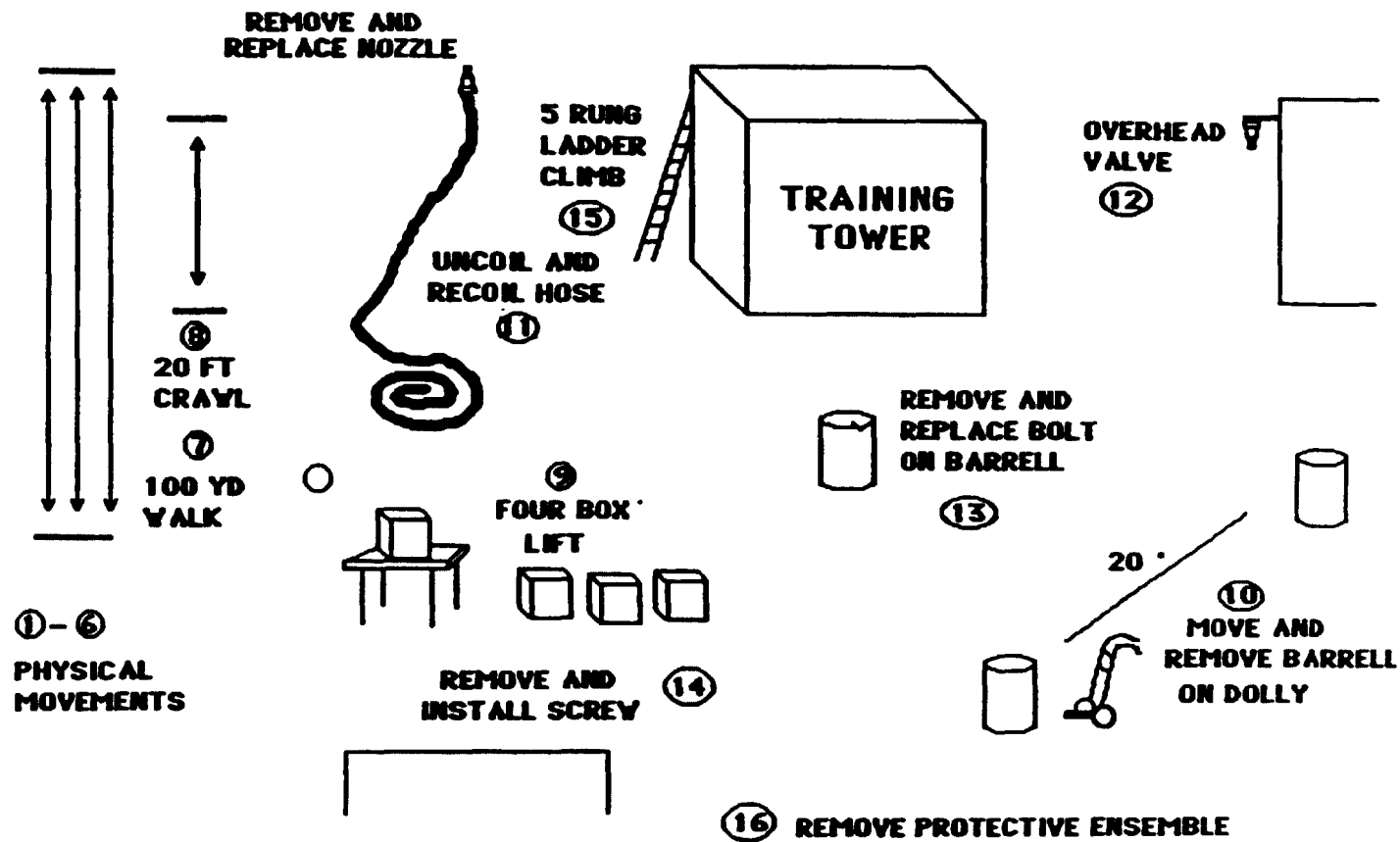


FIG. 1. ASTM WORK TASKS IN PROCEDURES A AND B

Phase 2: Anthropometric Assessment:

Anthropometric Measurement: A series of anthropometric measurements were taken on each subject while dressed in shorts and a T shirt with an anthropometer. The measurements selected included a group of traditional dimensions, e.g., height, weight, sitting height, chest circumference, hip circumference, etc., and a group of tailoring dimensions to include those used in the HAZMAT clothing. Twenty dimensions were selected prior to the experiments. The anthropometry enabled comparison of the size characteristics of our small sample internally, as well as with data from major U.S. Surveys on file in Anthropology Research Project's data bank.

Mobility Assessment: Following completion of the anthropometric measurements, each subject was asked to perform a series of carefully controlled body movement patterns designed to demonstrate segmental and whole body mobility. These ten measurements were taken while the fire fighters were dressed in shorts and a T shirt as well as fully dressed in the HAZMAT clothing with SCBA.

Movement patterns selected attempted to isolate motions involving simple joints (elbow, knee), complex joints (hip, shoulder) and those requiring combinations of multiple joints of both types. Insofar as it is feasible, movement patterns mimicked those required by fire fighters in the performance of their jobs.

The measurements of the range of motion associated with a given movement were made using two techniques which require minimal instrumentation. One technique requires only the measurement of the change in linear distance between definable locations on the body and fixed reference points over the course of the movement pattern. Only simple devices, such as a measuring tape, a measuring stick, or an anthropometer, are required for this method. Definitions of joint centers of rotation are not required. Examples of this technique are: the measurement of the distance from the top of the head (without helmet) to the floor during a deep-knee bend; the distance from the floor to the sole of the shoe at the completion of a standing leg lift; distance from the floor of the extended third digit during a maximum anterior flexion of the torso (knees locked). Subjects were encouraged to exert equal levels of effort during each repetition of a given maneuver. Postural effects on measurements of this type were minimized by careful attention to subject positioning by the investigators.

The second method of measurement, which may be used independently or in tandem with the first technique, involves the use of a gravity actuated device called a flexometer (Leighton 1955). This device features a circular dial calibrated in degrees which is free to rotate through 360° when attached to a moving body part. An adjustable web strap permits attachment over radii of various sizes. The difference in the degrees indicated at the beginning and end of a movement represents the arc traversed. Use of the flexometer expanded the variety of movement patterns that may be used in the tests. Simultaneous use of both measurement procedures provided two indices of a given movement. Most movements were replicated on-line to demonstrate the amount of variability inherent in mobility measurements. A minimum of two properly executed maneuvers were completed for each mobility movement by each subject. The mean value of the two best efforts were used as the basis of comparison in the evaluation. Two investigators worked as a team with one directing the subject, while reading, and reporting measurement values to the second who recorded the measurements and served as the observer-controller of subject positioning. Subjects were instructed to assume a standard starting posture before entering each maneuver.

RESULTS

The fire fighters' physiological responses increased markedly while wearing the fully encapsulated chemical protective ensemble compared to wearing only the station uniform. The impact of the environmental parameters on the physiologic variables varies from no change to a significant difference. All individual data have been tabulated and recorded on summary sheets in Appendix A. Figures 2 A, B, and C show the effect of the four climatic conditions and clothing on the fire fighter's heart rate. Figure 2 A shows the final heart rate taken at the end of the last work bout while Figure 2 B shows the change in heart rate (the final heart rate minus the resting, control heart rate). This change in heart rate nulls the data in a sense as it removes the variability in resting values due to level of physical fitness, time of day and other variables. Figure 2 C averages the heart rates according to climate and clothing. Both absolute values and heart rate changes are plotted. Tables 3 and 4 list the heart rate data. Figure 3 A, B, C and D show the changes in the fire fighter's body temperature with exposure to different climatic conditions while wearing the various protective clothing. As with heart rate, Figure 3 A shows the final body or rectal temperatures while Figure 3 B shows the change in temperature between the final and control values. Figures 3 C and D shows the average absolute body temperatures and the changes in body temperature across climatic conditions and clothing. Tables 5 and 6 list the actual individual rectal temperatures and rectal temperature changes.

The individual sweat losses are graphed in Figure 4 and tabulated in Table 7. Figure 5 shows the average moisture retention in the various clothing items worn by the fire fighter. The individual values for each fire fighter are listed in Tables 8, 9 and 10. Two inside Challenge garment temperatures were measured with thermistors taped just above and below the face piece of the protective shell. These two temperatures were averaged and individual values were plotted in Figure 6 and tabulated in Table 11. The individual fatigue ratings were calculated and the median values were plotted in Figure 7. The climatic conditions and work resulted in slightly fatigued scores for fire fighters dressed in the chemical protective garments with the exception of comfort conditions. Table 12 lists the absolute fatigue scores.

Table 13 lists the various environmental parameters measured during each test. Each value represents an average of 5 tests. As expected, some parameters varied significantly as a result of sudden weather shifts. Table 14 shows the drop in SCBA breathing air pressure for each fire fighter across climatic conditions and clothing. The air usage provides a rough estimate of the level of work and possible duration of work available per bottle. Table 15 tracks the starting body nude weights of the fire fighters for two or three consecutive days to determine any dehydration patterns.

Tables 16-19 lists and tabulates various anthropometric measurements. All individual anthropometric measures have been recorded on individual data sheets in Appendix B. Table 16 shows the loss in one and two hand over head reach when dressed in the inflated Challenge protective ensemble with SCBA. The overhead reach impairment is greater in two hand reach than the one hand reach. The loss of mobility or body movement is tabulated in Table 17 for five body movements. The weight of the SCBA affected all Of these measurements particularly the forward flexion of the torso at the waist. The added weight of the SCBA (35 lbs) pitched the body forward and the fire fighter had to be careful not to fall. Table 18 averages all the 8 data collected on all of the 20 fire fighters who participated in this study. Table 19 compares previous anthropometric data with various databases contained in the Anthropometric Research Project files. The Army database is the largest and most recent collection. The small fire fighters' database (N=20) is comparable to this large database.

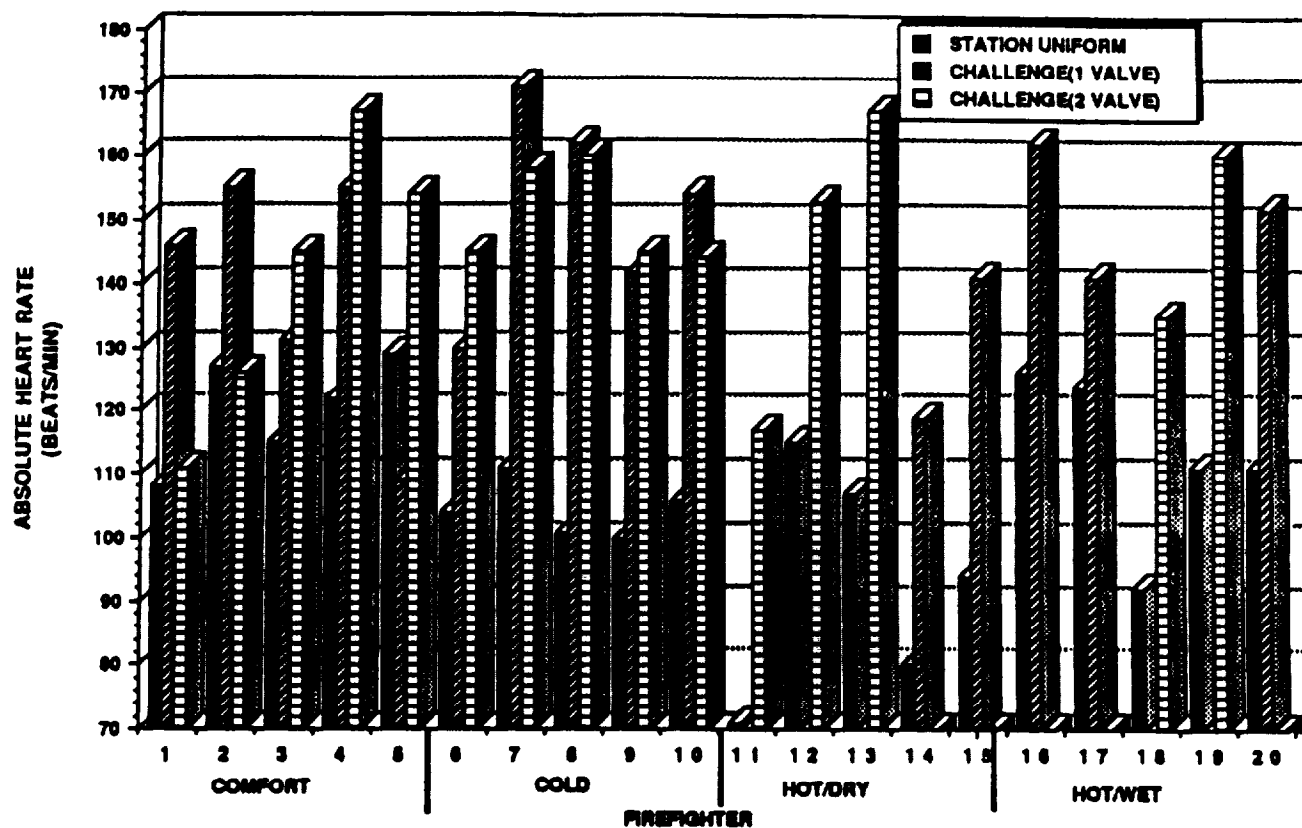


FIG.2A EFFECT OF WORK AND CLIMATIC CONDITIONS) ON ABSOLUTE HEART RATE.

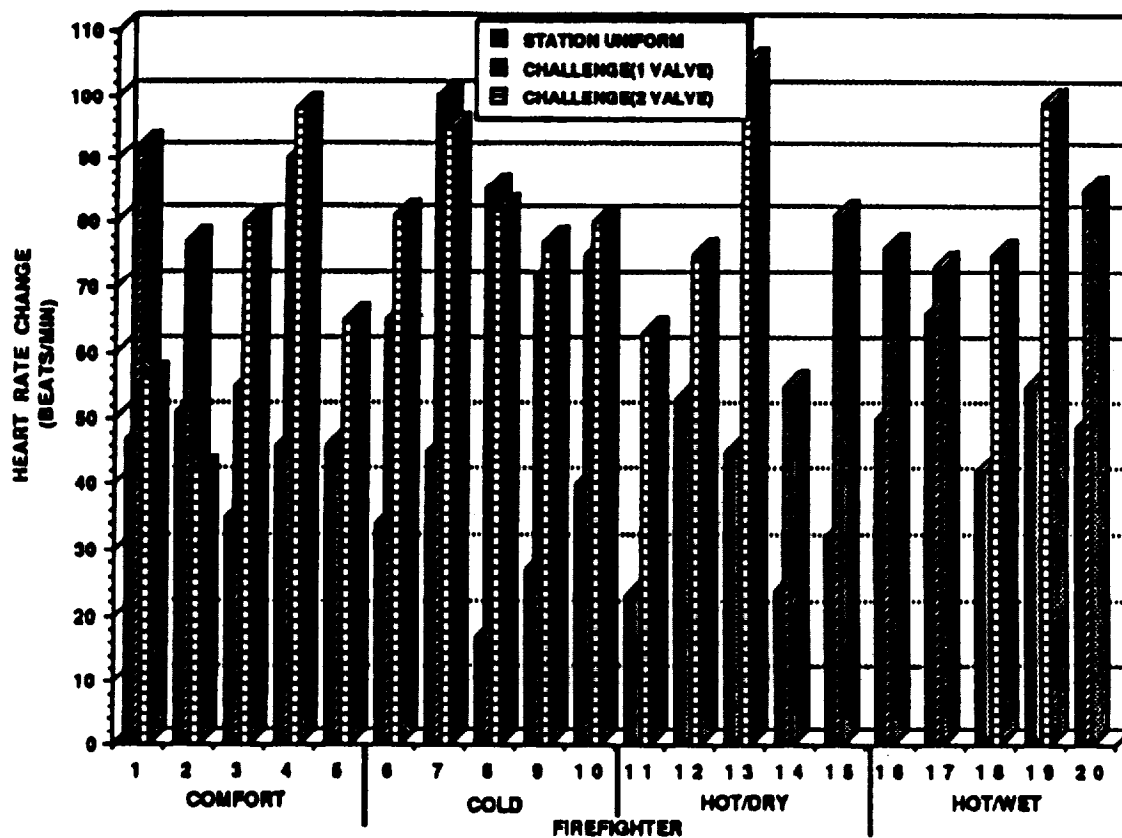


FIG.2B. EFFECT OF WORK AND CLIMATIC CONDITIONS ON HEART RATE CHANGE.

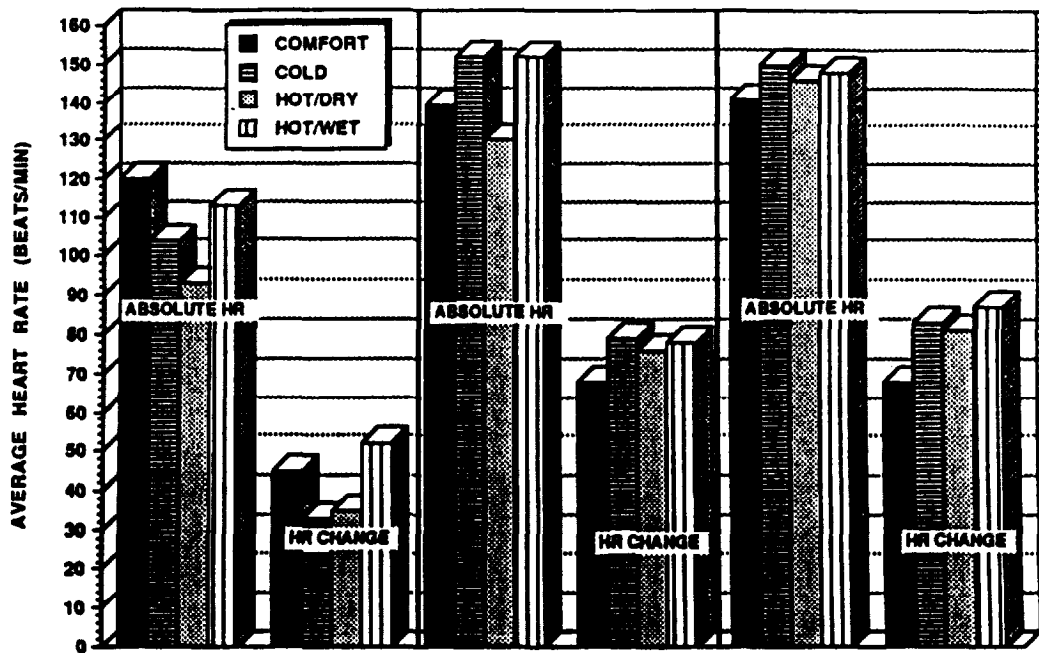


FIG.2C. EFFECT WORK AND CLIMATIC CONDITIONS ON HEART RATE.
(AVERAGE OF 5 SUBJECTS EACH CONDITION)

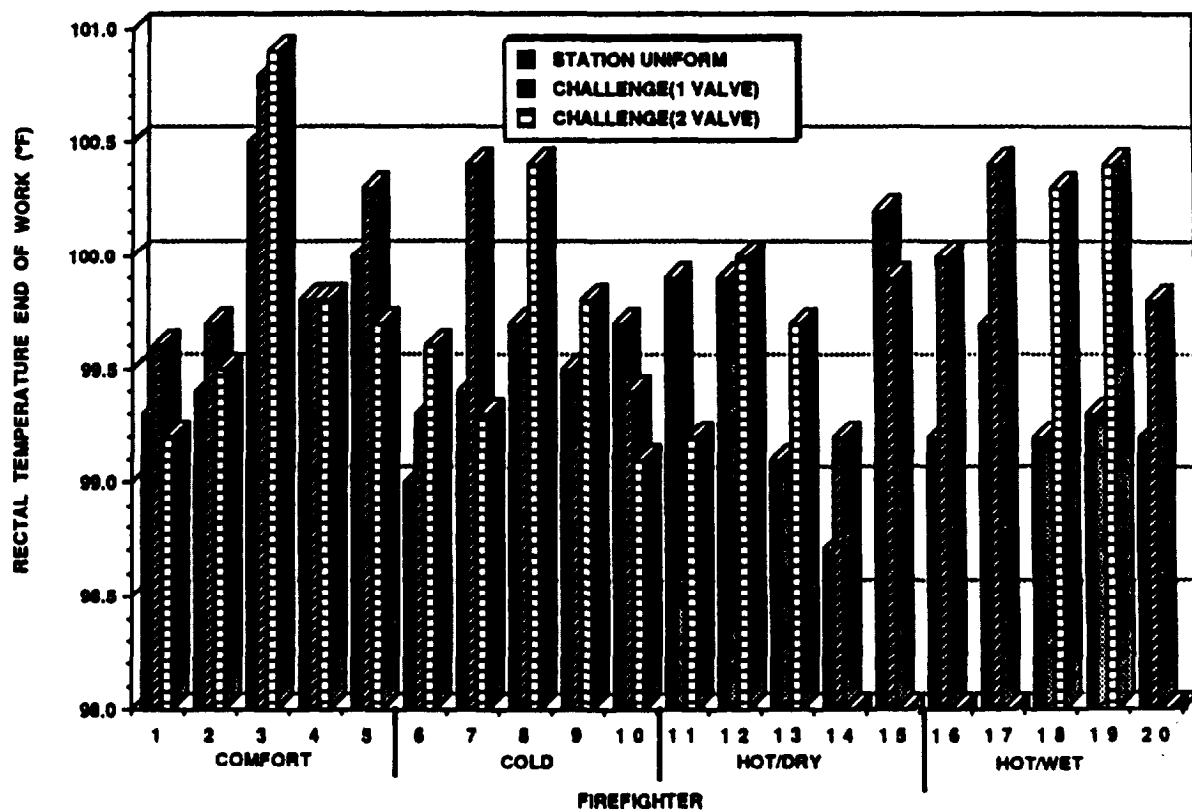


FIG.3A. EFFECT OF WORK AND CLIMATIC CONDITIONS ON ABSOLUTE RECTAL TEMPERATURE

TABLE 3. FINAL HR(BEAT 8/MIN)

FIREFIGHTER	CONDITIONS	STATION UNIFORM	CHALLENGE(1 VALVE)	CHALLENGE(2 VALVE)
1	COMFORT	108	148	111
2	COMFORT	127	155	128
3	COMFORT	115	131	145
4	COMFORT	122	155	167
5	COMFORT	129	109	154
	AVERAGE	120	139	141
	STAND. DEVIA.	± 9	± 20	± 22
6	COLD	104	130	145
7	COLD	111	171	158
8	COLD	101	182	160
9	COLD	100	142	145
10	COLD	106	154	144
	AVERAGE	104	152	150
	STAND. DEVIA.	± 4	± 18	± 8
11	HOT/DRY	71	0	117
12	HOT/DRY	115	0	153
13	HOT/DRY	107	0	167
14	HOT/DRY	80	119	0
15	HOT/DRY	94	141	0
	AVERAGE	83	130	148
	STAND. DEVIA.	± 18	± 15	± 28
16	HOT/WET	128	182	0
17	HOT/WET	124	141	0
18	HOT/WET	92	0	135
19	HOT/WET	111	0	180
20	HOT/WET	111	152	0
	AVERAGE	113	152	148
	STAND. DEVIA.	± 14	± 11	± 18

TABLE 4. HR CHANGE (BETA 8/MIN)

FIREFIGHTER	CONDITIONS	STATION UNIFORM	CHALLENGE(1 VALVE)	CHALLENGE(2 VALVE)
1	COMFORT	47	92	66
2	COMFORT	61	77	42
3	COMFORT	36	65	80
4	COMFORT	46	90	98
5	COMFORT	46	28	65
	AVERAGE	48	68	68
	STAND. DEVIA.	± 8	± 28	± 22
6	COLD	34	65	81
7	COLD	45	100	85
8	COLD	17	85	82
9	COLD	27	72	77
10	COLD	40	75	80
	AVERAGE	33	79	83
	STAND. DEVIA.	± 11	± 14	± 7
11	HOT/DRY	23	0	63
12	HOT/DRY	63	0	75
13	HOT/DRY	45	0	105
14	HOT/DRY	24	55	0
15	HOT/DRY	32	81	0
	AVERAGE	35	78	81
	STAND. DEVIA.	± 13	18	± 22
16	HOT/WET	50	78	0
17	HOT/WET	86	73	0
18	HOT/WET	42	0	75
19	HOT/WET	55	0	99
20	HOT/WET	49	85	0
	AVERAGE	62	78	67
	STAND. DEVIA.	± 9	± 8	± 17

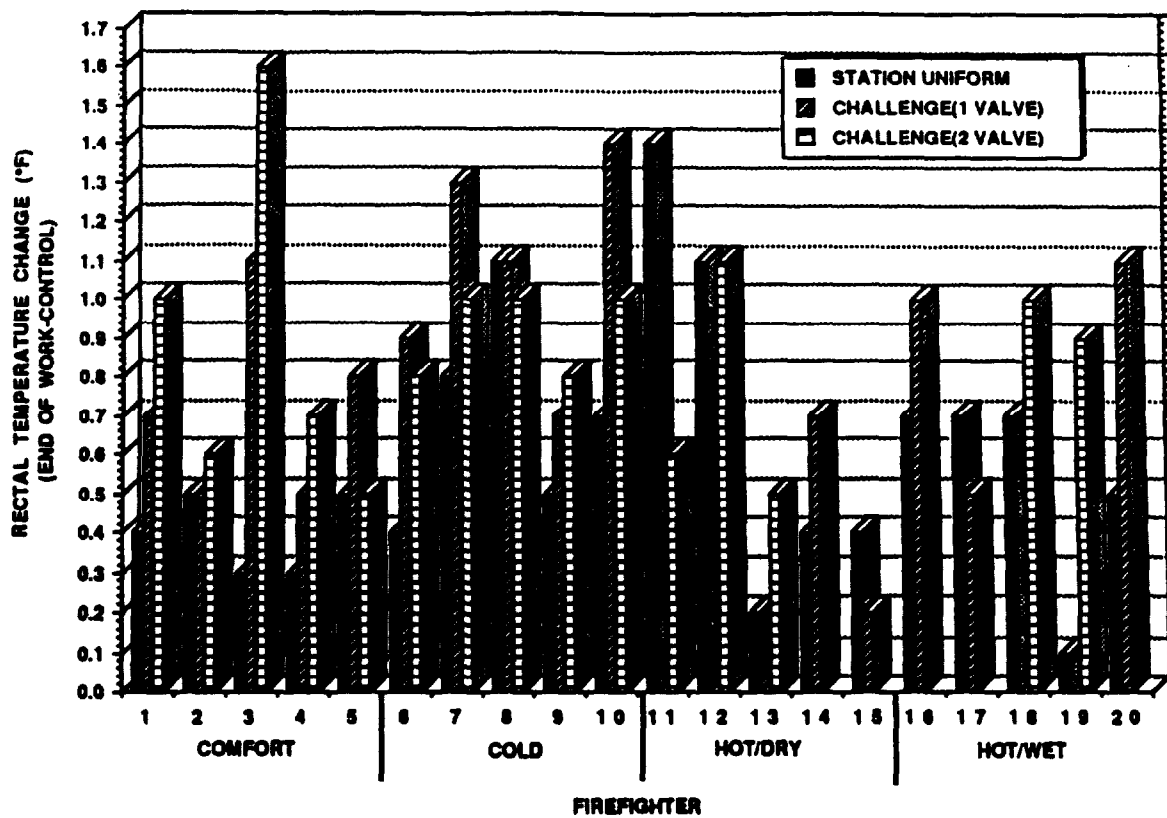


FIG.3B. EFFECT OF WORK AND CLIMATIC CONDITIONS ON RECTAL TEMPERATURE CHANGE

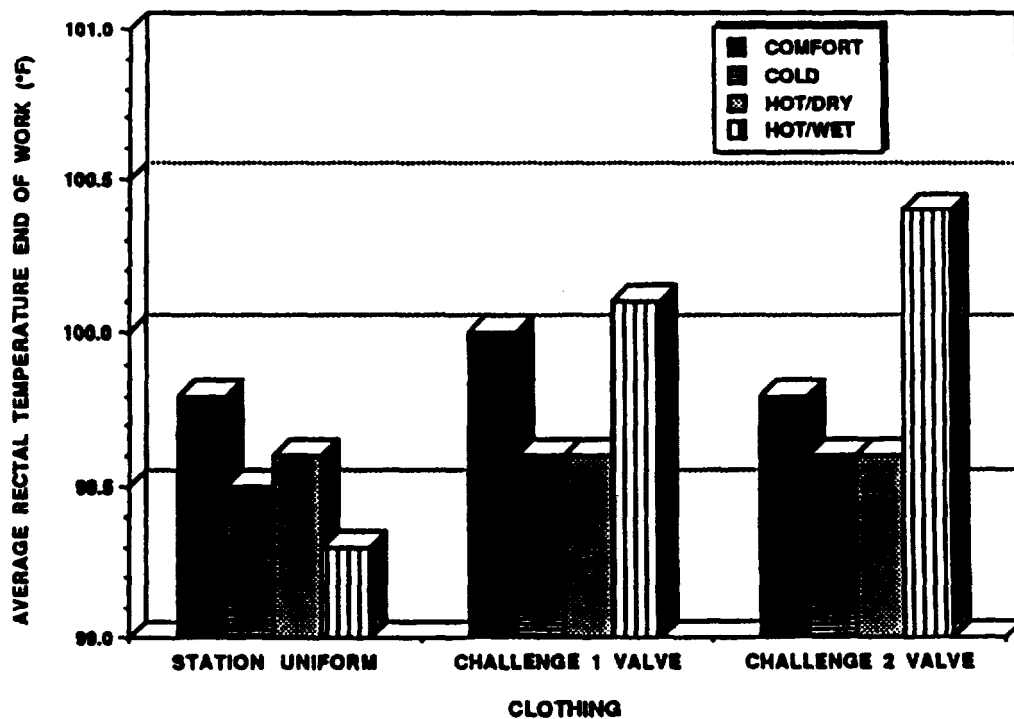


FIG.3C EFFECT WORK AND CLIMATIC CONDITIONS ON FINAL RECTAL TEMPERATURE.
(AVERAGE OF 5 SUBJECTS EACH CONDITION)

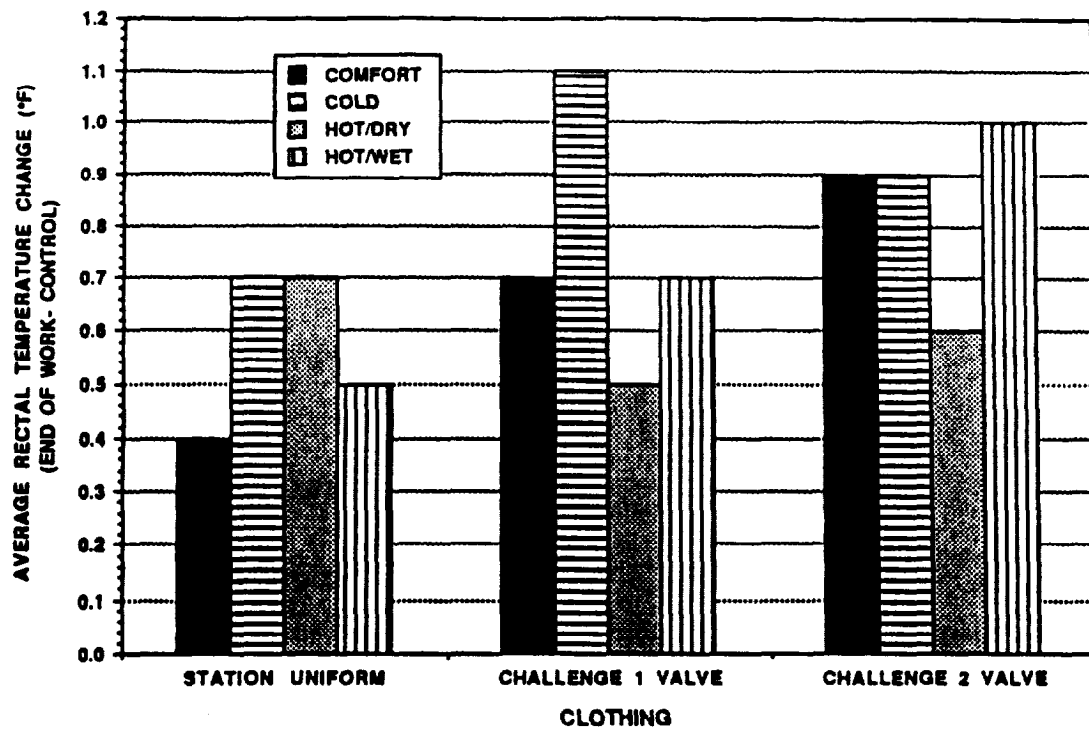


FIG.3D. EFFECT WORK AND CLIMATIC CONDITIONS ON RECTAL TEMPERATURE CHANGE (AVERAGE OF 5 SUBJECTS EACH CONDITION)

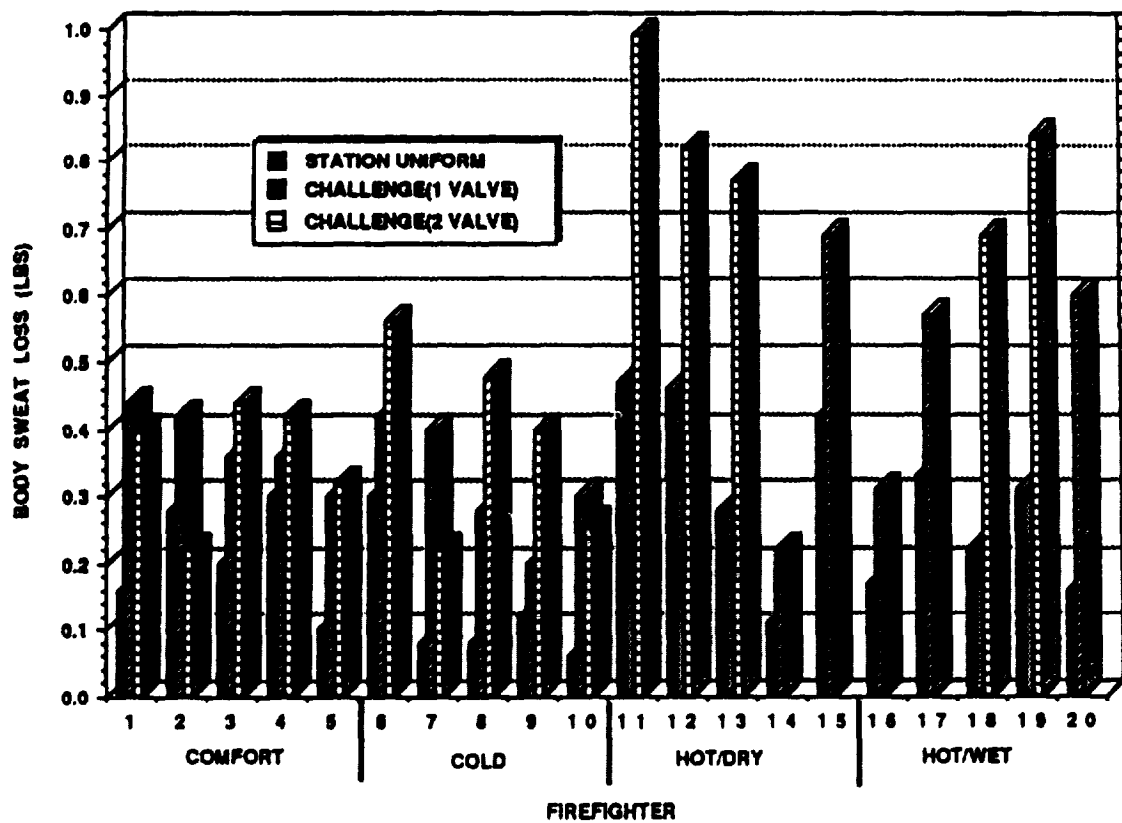


FIG.4. EFFECT WORK AND CLIMATIC CONDITIONS ON BODY WEIGHT LOSS.

TABLE 5. FINAL TR(*F)

FIREFIGHTER	CONDITIONS	STATION UNIFORM	CHALLENGE(1 VALVE)	CHALLENGE(2 VALVE)
1	COMFORT	99.3	99.6	99.2
2	COMFORT	99.4	99.7	99.5
3	COMFORT	100.5	100.8	100.9
4	COMFORT	99.8	99.8	99.8
5	COMFORT	100.0	100.3	99.7
	AVERAGE	99.8	100.0	99.8
	STAND. DEVI.	± 0.6	± 0.5	± 0.6
6	COLD	99.0	99.3	99.6
7	COLD	99.4	100.4	99.3
8	COLD	99.7	99.7	100.4
9	COLD	99.5	99.1	99.6
10	COLD	99.7	99.4	99.1
	AVERAGE	99.5	99.6	99.6
	STAND. DEVI.	± 0.3	± 0.5	± 0.5
11	HOT/DRY	99.9	0	99.2
12	HOT/DRY	99.9	0	100.0
13	HOT/DRY	99.1	0	99.7
14	HOT/DRY	99.7	99.2	0
15	HOT/DRY	100.2	99.9	0
	AVERAGE	99.8	99.6	99.6
	STAND. DEVI.	± 0.6	± 0.5	± 0.4
16	HOT/WET	99.2	100.0	0
17	HOT/WET	99.7	100.4	0
18	HOT/WET	99.2	0	100.3
19	HOT/WET	99.3	0	100.4
20	HOT/WET	99.2	99.6	0
	AVERAGE	99.3	100.1	100.4
	STAND. DEVI.	± 0.2	± 0.3	± 0.1

TABLE 6. FINAL TR(*F)

FIREFIGHTER	CONDITIONS	STATION UNIFORM	CHALLENGE(1 VALVE)	CHALLENGE(2 VALVE)
1	COMFORT	0.4	0.7	1.0
2	COMFORT	0.6	0.4	0.6
3	COMFORT	0.3	1.1	1.6
4	COMFORT	0.3	0.6	0.7
5	COMFORT	0.6	0.6	0.6
	AVERAGE	0.4	0.7	0.9
	STAND. DEVI.	± 0.1	± 0.3	± 0.4
6	COLD	0.4	0.9	0.6
7	COLD	0.8	1.3	1.0
8	COLD	1.1	1.1	1.0
9	COLD	0.5	0.7	0.6
10	COLD	0.7	1.4	1.0
	AVERAGE	0.7	1.1	0.9
	STAND. DEVI.	± 0.3	± 0.3	± 0.1
11	HOT/DRY	1.4	0	0.6
12	HOT/DRY	1.1	0	1.1
13	HOT/DRY	0.2	0	0.5
14	HOT/DRY	0.4	0.7	0
15	HOT/DRY	0.4	0.2	0
	AVERAGE	0.7	0.6	0.6
	STAND. DEVI.	± 0.6	± 0.4	± 0.3
16	HOT/WET	0.7	1.0	0
17	HOT/WET	0.7	0.6	0
18	HOT/WET	0.7	0	1.0
19	HOT/WET	0.1	0	0.9
20	HOT/WET	0.6	1.1	0
	AVERAGE	0.5	0.7	1.0
	STAND. DEVI.	± 0.3	± 0.3	± 0.1

TABLE 7. NUDE WEIGHT LOSS (LBS)

FIREFIGHTER	CONDITIONS	STATION UNIFORM	CHALLENGE(1 VALVE)	CHALLENGE(2 VALVE)
1	COMFORT	0.16	0.44	0.40
2	COMFORT	0.28	0.42	0.22
3	COMFORT	0.20	0.36	0.44
4	COMFORT	0.30	0.36	0.42
5	COMFORT	0.10	0.30	0.32
	AVERAGE	0.21	0.38	0.36
	STAND. DEVIA.	± 0.08	0.06	0.09
6	COLD	0.30	0.42	0.56
7	COLD	0.08	0.40	0.22
8	COLD	0.08	0.28	0.48
9	COLD	0.12	0.20	0.40
10	COLD	0.06	0.30	0.26
	AVERAGE	0.13	0.32	0.38
	STAND. DEVIA.	± 0.10	± 0.09	0.14
11	HOT/DRY	0.47	0.00	0.99
12	HOT/DRY	0.46	0.00	0.82
13	HOT/DRY	0.28	0.00	0.77
14	HOT/DRY	0.11	0.22	0.00
15	HOT/DRY	0.42	0.69	0.00
	AVERAGE	0.35	0.45	0.66
	STAND. DEVIA.	± 0.15	± 0.33	± 0.12
16	HOT/WET	0.17	0.31	0.00
17	HOT/WET	0.33	0.57	0.00
18	HOT/WET	0.22	0.00	0.69
19	HOT/WET	0.31	0.00	0.64
20	HOT/WET	0.16	0.60	0.00
	AVERAGE	0.24	0.49	0.60
	STAND. DEVIA.	± 0.06	± 0.16	0.16

TABLE 8 SWEAT STAT UNIF-LBS

FIREFIGHTER	CONDITIONS	T-SHIRT	SHORTS	STATION SHIRT	STATION PANT	COVERALLS	SOCKS	BOOTS
1	COMFORT	0.02	0.02	0.00	0.00	0.02	0.00	0.00
2	COMFORT	0.02	0.02	0.02	0.00	0.00	0.00	0.00
3	COMFORT	0.04*	0.00	0.02	0.00	0.02	0.00	0.00
4	COMFORT	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	COMFORT	0.02	0.00	0.00	0.00	0.00	0.00	0.00
	AVERAGE	0.01	0.01	0.01	0.00	0.01	0.00	0.00
	STAND. DEVIA.	± 0.01	± 0.01	± 0.01	± 0.00	± 0.01	± 0.00	± 0.00
6	COLD	0.00	0.00	0.00	0.00	0.02	0.00	0.00
7	COLD	0.00	0.00	0.00	0.00	0.00	0.02	0.00
8	COLD	0.00	0.02	0.00	0.02	0.00	0.00	0.00
9	COLD	0.00	0.00	0.00	0.00	0.04	0.02	0.00
10	COLD	0.02	0.00	0.02	0.02	0.00	0.00	0.02
	AVERAGE	0.00	0.00	0.00	0.01	0.01	0.01	0.00
	STAND. DEVIA.	± 0.01	± 0.00	± 0.01	± 0.01	± 0.02	± 0.01	± 0.01
11	HOT/DRY	0.02	0.00		0.02		0.02	0.01
12	HOT/DRY	0.02	0.00		0.02		0.02	0.00
13	HOT/DRY	0.04	0.02		0.00		0.02	0.00
14	HOT/DRY	0.00	0.02		0.00		0.00	0.00
15	HOT/DRY	0.03	0.02		0.00		0.00	0.02
	AVERAGE	0.02	0.01		0.01		0.01	0.01
	STAND. DEVIA.	± 0.01	± 0.01		± 0.01		± 0.01	± 0.01
16	HOT/WET	0.00	0.00			0.00	0.00	0.00
17	HOT/WET	0.07	0.02			0.09	0.03	0.00
18	HOT/WET	0.02	0.02			0.00	0.00	0.00
19	HOT/WET	0.04	0.02			0.00	0.02	0.00
20	HOT/WET	0.02	0.00			0.02	0.03	0.00
	AVERAGE	0.03	0.01			0.02	0.02	0.00
	STAND. DEVIA.	± 0.03	± 0.01			± 0.04	± 0.02	± 0.00

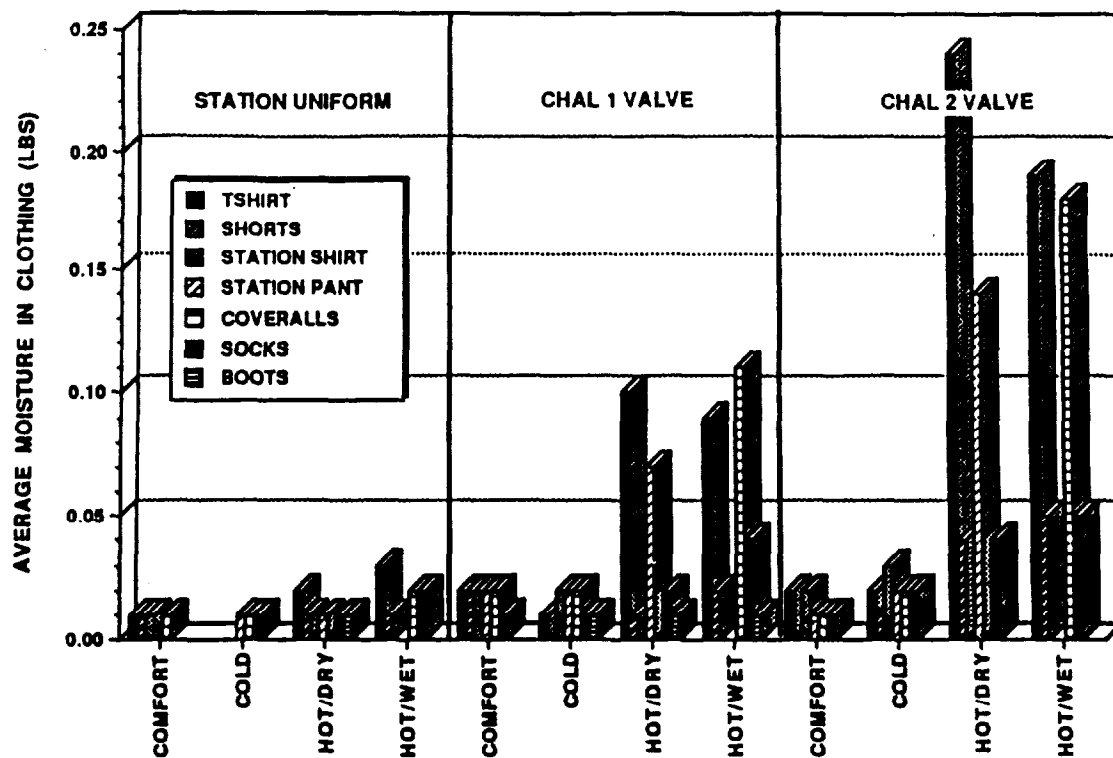


FIG.5. MOISTURE ACCUMULATION IN CLOTHING

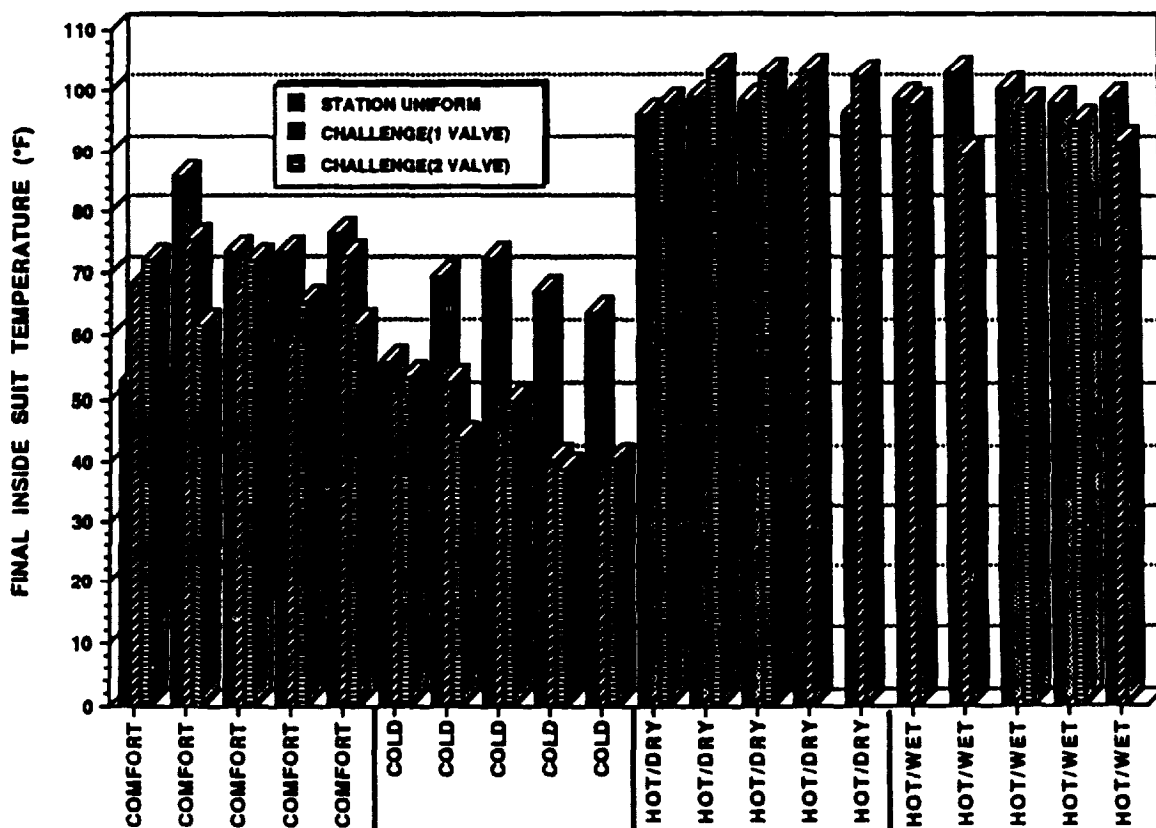


FIG.6. AVERAGE FINAL INSIDE CLOTHING TEMPERATURES.

TABLE 9. SWEAT CHAL/1VALVE-LBS

FIREFIGHTER	CONDITIONS	TSHIRT	SHORTS	STATION SHIRT	STATION PANT	COVERALLS	SOCKS	BOOTS
1	COMFORT	0.02	0.00	0.02	0.02	0.02	0.00	0.00
2	COMFORT	0.02	0.00	0.02	0.02	0.02	0.02	0.00
3	COMFORT	0.02*	0.02	0.00	0.02	0.04	0.02	0.00
4	COMFORT	0.00	0.04	0.02	0.06	0.02	0.02	0.00
5	COMFORT	0.04	0.00	0.02	0.00	0.00	0.00	0.00
	AVERAGE	0.02	0.02	0.02	0.02	0.02	0.01	0.00
	STAND. DEVIA.	± 0.02	± 0.02	± 0.01	± 0.03	± 0.01	± 0.01	± 0.00
	* INCLUDES BRA							
6	COLD	0.02	0.00	0.04	0.02	0.04	0.02	0.02
7	COLD	0.02	0.00	0.00	0.02	0.02	0.02	0.00
8	COLD	0.00	0.00	0.00	0.02	0.02	0.01	0.02
9	COLD	0.00	0.00	0.02	0.02	0.02	0.02	0.00
10	COLD	0.00	0.00	0.02	0.00	0.02	0.00	0.02
	AVERAGE	0.01	0.00	0.02	0.02	0.02	0.01	0.01
	STAND. DEVIA.	± 0.01	± 0.00	± 0.02	± 0.02	± 0.01	± 0.01	± 0.01
11	HOT/DRY							
12	HOT/DRY							
13	HOT/DRY							
14	HOT/DRY	0.02	0.00		0.03		0.00	0.02
15	HOT/DRY	0.17	0.02		0.11		0.04	0.00
	AVERAGE	0.10	0.01		0.07		0.02	0.01
	STAND. DEVIA.	± 0.10	± 0.01		± 0.06		± 0.03	± 0.01
16	HOT/WET	0.05	0.00			0.07	0.03	0.00
17	HOT/WET	0.11	0.02			0.15	0.03	0.00
18	HOT/WET							
19	HOT/WET							
20	HOT/WET	0.11	0.03			0.11	0.05	0.02
	AVERAGE	0.09	0.02			0.11	0.04	0.01
	STAND. DEVIA.	± 0.03	± 0.02			± 0.04	± 0.01	± 0.01

TABLE 10. SWEAT CHAL/2VALVE-LBS

FIREFIGHTER	CONDITIONS	TSHIRT	SHORTS	STATION SHIRT	STATION PANT	COVERALLS	SOCK	BOOTS
1	COMFORT	0.02	0.00	0.02	0.04	0.00	0.00	0.00
2	COMFORT	0.00	0.00	0.04	0.02	0.00	0.00	0.00
3	COMFORT	0.02*	0.00	0.02	0.02	0.02	0.02	0.00
4	COMFORT	0.02	0.00	0.02	0.02	0.04	0.04	0.00
5	COMFORT	0.02	0.00	0.02	0.00	0.02	0.00	0.00
	AVERAGE	0.02	0.00	0.02	0.01	0.01	0.01	0.00
	STAND. DEVIA.	± 0.00	± 0.00	± 0.01	± 0.02	± 0.02	±	± 0.00
	* INCLUDES BRA							
6	COLD	0.06	0.02	0.06	0.04	0.06	0.02	0.00
7	COLD	0.02	0.00	0.00	0.02	0.00	0.00	0.00
8	COLD	0.04	0.02	0.02	0.02	0.04	0.02	0.00
9	COLD	0.00	0.00	0.04	0.02	0.00	0.02	0.00
10	COLD	0.00	0.00	0.02	0.02	0.02	0.00	0.00
	AVERAGE	0.02	0.01	0.03	0.02	0.02	0.02	0.00
	STAND. DEVIA.	± 0.03	± 0.01	± 0.02	± 0.01	± 0.03	±	± 0.00
11	HOT/DRY	0.33	0.02		0.18		0.04	0.00
12	HOT/DRY	0.20	0.06		0.11		0.04	0.00
13	HOT/DRY	0.20	0.05		0.13		0.05	0.00
14	HOT/DRY							
15	HOT/DRY							
	AVERAGE	0.24	0.04		0.14		0.04	0.00
	STAND. DEVIA.	± 0.06	± 0.02		± 0.04		±	± 0.00
16	HOT/WET							
17	HOT/WET							
18	HOT/WET	0.13	0.05			0.15	0.05	0.00
19	HOT/WET	0.24	0.04			0.20	0.05	0.00
20	HOT/WET							
	AVERAGE	0.19	0.05			0.18	0.05	0.00
	STAND. DEVIA.	± 0.06	± 0.01			± 0.04	±	± 0.00

TABLE 11. INSIDE CLOTH TEMP(*F)

FIREFIGHTER	CONDITIONS	STATION UNIFORM	CHALLENGE(1 VALVE)	CHALLENGE(2 VALVE)
1	COMFORT	53.0	68.5	72.0
2	COMFORT	66.0	75.5	81.8
3	COMFORT	73.4	68.1	72.2
4	COMFORT	73.3	59.3	65.4
5	COMFORT	76.5	72.8	61.8
	AVERAGE	72.4	68.8	66.6
	STAND. DEVIA.	± 12.0	± 6.2	± 4.6
6	COLD	55.8	51.8	53.2
7	COLD	69.4	52.5	43.5
8	COLD	72.3	42.1	49.5
9	COLD	67.0	40.3	38.4
10	COLD	63.7	36.7	40.4
	AVERAGE	65.6	44.7	45.0
	STAND. DEVIA.	± 6.3	± 7.1	± 6.2
11	HOT/DRY	98.0		97.7
12	HOT/DRY	99.1		103.4
13	HOT/DRY	98.4		102.6
14	HOT/DRY	100.3	103.2	
15	HOT/DRY	96.1	102.4	
	AVERAGE	98.0	102.8	101.2
	STAND. DEVIA.	± 1.9	± 0.6	± 3.1
16	HOT/WET	98.5	97.6	
17	HOT/WET	102.9	89.6	
18	HOT/WET	100.2		97.6
19	HOT/WET	97.9		94.8
20	HOT/WET	98.5	91.6	
	AVERAGE	99.6	92.9	96.2
	STAND. DEVIA.	± 2.0	± 4.2	± 2.0

TABLE 12. FATIGUE RATINGS

	COMFORT	COMFORT	COLD	HOT/DRY	HOT/WET
STATION UNIFORM		3.00	2.00	3.50	3.33
CHALLENGE 1 VALVE		3.25	9.00	6.50	7.00
CHALLENGE 2 VALVE		4.33	7.00	6.50	7.00

TABLE 13. SUMMARY OF CLIMATIC CONDITIONS

	ENVIRONMENTAL PARAMETERS					
	DRY BULB (°F)	WET BULB (°F)	HUMIDITY (%RH)	GLOBE TEMP.(°F)	WBGT (° F)	WIND VEL. (MPH)
A. COMFORT						
1. STAT.UNIF	63.2	54.8	61	73.0	59.3	3.3
2. CHAL 1VAL	61.5	50.4	46	71.2	55.6	9.1
3. CHAL 2VAL	57.0	49.2	58	67.5	53.6	5.1
AVERAGE	60.6	51.5	55	70.6	56.2	5.8
B. COLD						
1. STAT.UNIF	42.5	38.0	67	51.9	41.3	1.9
2. CHAL 1VAL	30.1	28.1	59	31.7	29.6	2.1
3. CHAL 2VAL	32.1	29.3	60	33.6	31.7	2.3
AVERAGE	34.2	31.8	62	39.1	34.2	2.1
C. HOT/DRY						
1. STAT.UNIF	99.6	76.4	35	116.9	86.7	3.2
2. CHAL 1VAL	97.8	74.8	35	118.9	86.1	5.2
3. CHAL 2VAL	97.5	75.5	37	116.4	86.1	6.5
AVERAGE	98.3	75.6	36	117.4	86.3	5.0
D. HOT/WET						
1. STAT.UNIF.	92.3	81.4	61	114.5	89.0	3
2. CHAL 1VAL	93.4	81.6	61	118.3	90.4	3
3. CHAL 2VAL	92.6	81.7	65	117.7	90.3	3
AVERAGE	92.8	81.6	62	116.8	89.9	3

TABLE 14 SCBA PRESS.DROP(PSI)

FIREFIGHTER	CONDITIONS	STATION UNIFORM	CHALLENGE 1 VALVE	CHALLENGE 2 VALVE
1	COMFORT	NOT USED	1600	1700
2	COMFORT	NOT USED	1700	1800
3	COMFORT	NOT USED	2000	2200
4	COMFORT	NOT USED	1750	1700
5	COMFORT	NOT USED	1700	1750
	AVER	NA	1750	1830
	STAND DEV	NA	± 150	± 211
6	COLD	NOT USED	1500	1400
7	COLD	NOT USED	2500	1400
8	COLD	NOT USED	1400	1700
9	COLD	NOT USED	1400	2000
10	COLD	NOT USED	1700	1900
	AVER	NA	1700	1680
	STAND DEV	NA	± 464	± 277
11	HOT/DRY	NOT USED		1100
12	HOT/DRY	NOT USED		1900
13	HOT/DRY	NOT USED		1400
14	HOT/DRY	NOT USED	1050	
15	HOT/DRY	NOT USED	1100	
	AVER	NA	1075	1467
	STAND DEV	NA	± 35	± 404
16	HOT/WET	NOT USED	1600	
17	HOT/WET	NOT USED	2100	
18	HOT/WET	NOT USED		2000
19	HOT/WET	NOT USED		1400
20	HOT/WET	NOT USED	1800	
	AVER	NA	1833	1700
	STAND DEV	NA	± 252	± 424

TABLE 15. DAILY BODY WIEIGHT-LBS

CONDITIONS	CONDITIONS	TEST DAY 1	TEST DAY 2	TEST DAY 3	DAY 1- FINAL DAY
1	COMFORT	172.64	171.54	169.38	-3.26
2	COMFORT	170.54	180.34	181.52	1.98
3	COMFORT	182.38	181.70	184.00	1.64
4	COMFORT	198.10	193.62	193.40	-2.70
5	COMFORT	194.58	193.62	192.64	-1.92
6	COLD	211.34	212.62	210.38	-0.98
7	COLD	175.16	174.50	176.90	1.74
8	COLD	181.82	181.62	182.58	0.76
9	COLD	194.48	194.72	193.90	-0.58
10	COLD	178.90	175.12	180.32	1.42
11	HOT/DRY	185.38	185.05		-0.31
12	HOT/DRY	238.69	239.88		1.17
13	HOT/DRY	217.59	219.49		1.90
14	HOT/DRY	174.48	175.22		0.77
15	HOT/DRY	183.44	184.22		0.78
16	HOT/WET	174.98	174.25		-0.71
17	HOT/WET	201.43	203.11		1.68
18	HOT/WET	138.18	138.49		-1.69
19	HOT/WET	160.41	162.50		2.09
20	HOT/WET	178.48	172.18		-4.28

TABLE 16. CHAL-NUDE REACH(IN)

CONDITIONS	FIREFIGHTER	1 ARM UP	2 ARMUP
COMFORT	1	-2.0	-2.6
COMFORT	2	-1.3	-2.4
COMFORT	3	-1.6	-8.7
COMFORT	4	-1.5	-4.0
COMFORT	5	-1.8	-5.6
COLD	6	-2.3	-3.8
COLD	7	-0.2	-0.2
COLD	8	-2.3	-4.7
COLD	9	-2.7	-3.2
COLD	10	-1.0	1.5
HOT/DRY	11	-0.1	-0.8
HOT/DRY	12	-0.3	-0.4
HOT/DRY	13	-3.5	-3.9
HOT/DRY	14	-0.8	-1.8
HOT/DRY	15	-0.1	-0.7
HOT/WET	16	-0.8	-1.1
HOT/WET	17	-0.9	-1.6
HOT/WET	18	-0.6	-0.6
HOT/WET	19	-1.4	-2.4
HOT/WET	20	-2.4	-3.1
AVERAGE		-1.4	-2.7
STAND.DEVIA.		± 1.0	± 2.1

TABLE 17.CHAL-NUDE MOTION(*)

CONDITION	FIREFIGHTER	ELBOW FLEX	SHOULDER FLEX	BEND FORWARD	BEND RIGHT	BEND LEFT
COMFORT	1	-26	-23	-4.7	+4.3	+3.4
COMFORT	2	+10	0	-8.2	+9.8	-0.2
COMFORT	3	-38	-21	-24	+3.9	-5.2
COMFORT	4	-12	-21	0	+8.3	+8.2
COMFORT	5	-13	-31	-3.2	-1.7	-3.9
COLD	6	-18	-6	-21	-17	-22
COLD	7	-14	-21	-12	-25	-9
COLD	8	+10	-5	-16	-15	-23
COLD	9	-2	+9	-17	-12	-1
COLD	10	-13	-21	-36	-25	-16
HOT/DRY	11	+4	+16	-7	-21	-16
HOT/DRY	12	+8	-5	-1	-15	-15
HOT/DRY	13	+4	+4	-8	+1	-7
HOT/DRY	14	-10	+5	-6	-7	-13
HOT/DRY	15	-2	0	-14	0	-9
HOT/WET	16	-3	-15	-13	-12	-5
HOT/WET	17	0	-2	-17	-16	-12
HOT/WET	18	+10	+19	-8	-16	-5
HOT/WET	19	+7	+3	-43	-13	-19
HOT/WET	20	-3	-8	-21	-13	-8
-2.5	AVERAGE	-2.5	-6.1	-14.0	-9.2	-9.0

TABLE 18. AVERAGES FOR ALL ANTHROPOMETRIC MEASUREMENTS

CONTROL		PROTECTIVE CLOTHING	
CLOTHING WORN: UNDERWEAR, STATION UNIFORM, SOCKS		UNDERWEAR, STATION UNIFORM, SCBA, CHALLENGE SUIT, SOCKS, BOOTS	
1. WEIGHT (LBS)	184.7	1. WEIGHT (LBS)	
2. STATURE (*)	71.3	2. STATURE (*)	75.7
3. AXILLARY HEIGHT	52.9	3. AXILLARY HEIGHT	51.1
4. CROTCH HEIGHT	33.1	4. CROTCH HEIGHT	29.8
5. FOREARM-FOREARM BRDTH	20.0	5. FOREARM-FOREARM BROTH	29.5
6. SHOULDER BROTH	17.2	6. SHOULDER BRDTH	28.1
7. CHEST BROTH	12.6	7. CHEST BRDTH	17.9
8. HIP BROTH	12.7	8. HIP BRDTH	16.6
9. SCYE HEIGHT	5.3	9. SCYE HEIGHT	7.5
10. CHEST DEPTH	9.5	10. CHEST DEPTH	25.0
11. BUTT DEPTH	9.2	11. BUTT DEPTH	17.2
12. SLEEVE INSEAM	20.3	12. SLEEVE INSEAM	20.2
13. SCYE CIRCUMFERENCE	19.3	13. SCYE CIRCUMFERENCE	29.2
14. ARM CIRC. AT SCYE	14.3	14. ARM CIR. AT SCYE	26.8
15. CHEST CIRC. AT NIPPLE	40.5	15. CHEST CIR. AT NIPPLE	80.7
16. BUTT CIRCUMFERENCE	41.0	16. BUTT CIRCUMFERENCE	57.7
17. THIGH CIRCUMFERENCE	23.9	17. THIGH CIRCUMFERENCE	36.4
18. SITTING HEIGHT	37.4	18. SITTING HEIGHT	36.4
19. BUTT-KNEE LENGTH	23.4	19. BUTT-KNEE LENGTH	25.1
20. FOOT LENGTH	10.1	20. FOOT LENGTH	11.5
21. OVERHEAD GRIP-1 HAND	86.8	21. OVERHEAD GRIP-1 HAND	85.4
22. OVERHEAD GRIP-2 HANDS	85.3	22. OVERHEAD GRIP-2 HANDS	82.6
23. TORSO FLEX-FORWARD (°)	8.2	23. TORSO FLEX-FORWARD (°)	9.3
24. TORSO FLEX-LATERAL LT (°)	2.5	24. TORSO FLEX-LATERAL LT (°)	3.4
25. TORSO FLEX-LATERAL RT(°)	2.1	25. TORSO FLEX-LRTERAL RT(°)	3.2
26. SQUATTING HEIGHT	44.6	26. SQUATTING HEIGHT	53.3
27. LEG LIFT HEIGHT RIGHT		27. LEG LIFT HEIGHT RIGHT	
28. MAX STRIDE LENGTH	45.5	28. MAX STRIDE LENGTH	46.7
29. ELBOW FLEHION (°)	15.5	29. ELBOW FLEXION (°)	15.2
30. SHOULDER FLEXION (°)	17.4	30. SHOULDER FLEHION (°)	17.1

* ALL URLUES IN INCHES UNLESS OTHERWISE NOTED.

TABLE 19. MEANS AND STANDARD DEVIATIONS FOR THE ANTHROPOMETRY OF FIRE FIGHTER TEST SAMPLE AND FOUR COMPARABLE MALE POPULATIONS (INCHES)

	FIREFIGHTERS		MINERS		AIR TRAFFIC CONTROLLERS		AIR FORCE FLYERS		ARMY (1988)	
	X	S.D.	X	S.D.	X	S.D.	X	S.D.	X	S.D.
AGE (N=17) (YRS)	30.8	4.0	32.1	9.2	28.4	6.2	30.0	6.3	27.4	7.1
WEIGHT (LBS)	194.6	33.8	177.2	26.8	161.9	22.1	173.5	21.4	173.0	24.5
HEIGHT STANDING	71.1	3.1	68.4	2.7	69.6	2.4	69.8	2.4	69.1	2.6
EYE HEIGHT	32.4	1.1	--	--	32.2	1.3	31.9	1.2	31.2	1.4
ACROMIAL HEIGHT	58.3	3.4	55.9	2.4	57.9	2.3	57.2	2.3	56.8	2.4
SUPRASTERNAL HEIGHT	58.2	3.0	--	--	56.7	2.2	57.2	2.2	56.6	2.3
CERVICAL HEIGHT	60.3	3.0	58.9	2.4	59.2	2.3	59.9	2.3	59.8	2.5
CHEST HEIGHT	51.9	3.0	--	--	50.4	2.0	50.9	2.0	50.2	2.2
WAIST (HEIGHT)	42.5	2.2	40.9	2.1	41.7	2.0	41.9	1.9	41.7	2.0
BUTTOCK HEIGHT	36.0	1.9	--	--	--	--	35.5	1.7	34.9	1.9
CROTCH HEIGHT	33.0	1.7	--	--	--	--	33.5	1.7	33.0	1.8
MID-PATELLA HEIGHT	19.8	1.1	--	--	--	--	19.6	1.0	17.1	1.0
HEAD HEIGHT	8.7	0.5	--	--	--	--	9.0	0.4	9.1	0.4
BIDELTOID BREADTH	19.8	1.5	18.9	1.1	18.5	1.1	19.0	1.0	19.4	1.0
INTERSCYE	15.7	1.2	16.1	1.3	--	--	15.3	1.5	15.8	1.2
HIP BREADTH	14.1	1.0	--	--	13.7	0.7	13.9	0.7	13.5	0.8
HAND LENGTH	7.6	0.5	7.5	0.4	--	--	7.5	0.3	7.6	0.4
HEAD CIRC.	22.6	0.8	22.4	0.7	22.8	0.6	22.6	0.6	22.4	0.6
SHOULDER CIRC.	47.0	2.8	46.7	2.8	46.2	2.6	46.3	2.3	46.3	2.4
BICEPS CIRC.	13.1	1.6	13.6	1.1	11.8	1.1	12.9	0.9	13.3	1.1
FOREARM CIRC.	12.2	0.7	--	--	10.8	0.7	11.1	0.6	12.0	0.7
SCYE CIRC.	19.0	1.1	--	--	--	--	19.1	1.1	17.5	1.1
CHEST CIRC.(NIPPLE)	39.8	3.4	39.5	3.1	38.2	2.6	38.8	2.5	39.0	2.7
WAIST CIRC.(NAVEL)	36.6	4.1	35.9	4.1	--	--	34.5	2.9	34.0	3.4
HIP CIRC.(MAX BUTT)	40.4	3.1	38.7	2.8	38.1	2.4	38.8	2.2	38.7	2.5
UPPER THIGH CIRC.	23.4	2.2	22.2	1.9	--	--	23.1	1.7	23.5	1.9
CALF MAX CIRC.	15.4	1.1	14.6	1.1	14.4	0.9	14.6	0.9	14.9	1.0
SLEEVE LENGTH	34.8	2.1	--	--	--	--	35.7	1.4	34.9	1.5
SITTING HEIGHT	37.3	1.2	36.0	1.4	36.2	1.3	36.7	1.3	36.0	1.4
BUTTOCK-KNEE LENGTH	27.0	4.4	23.7	1.1	23.7	1.1	23.8	1.1	24.3	1.2

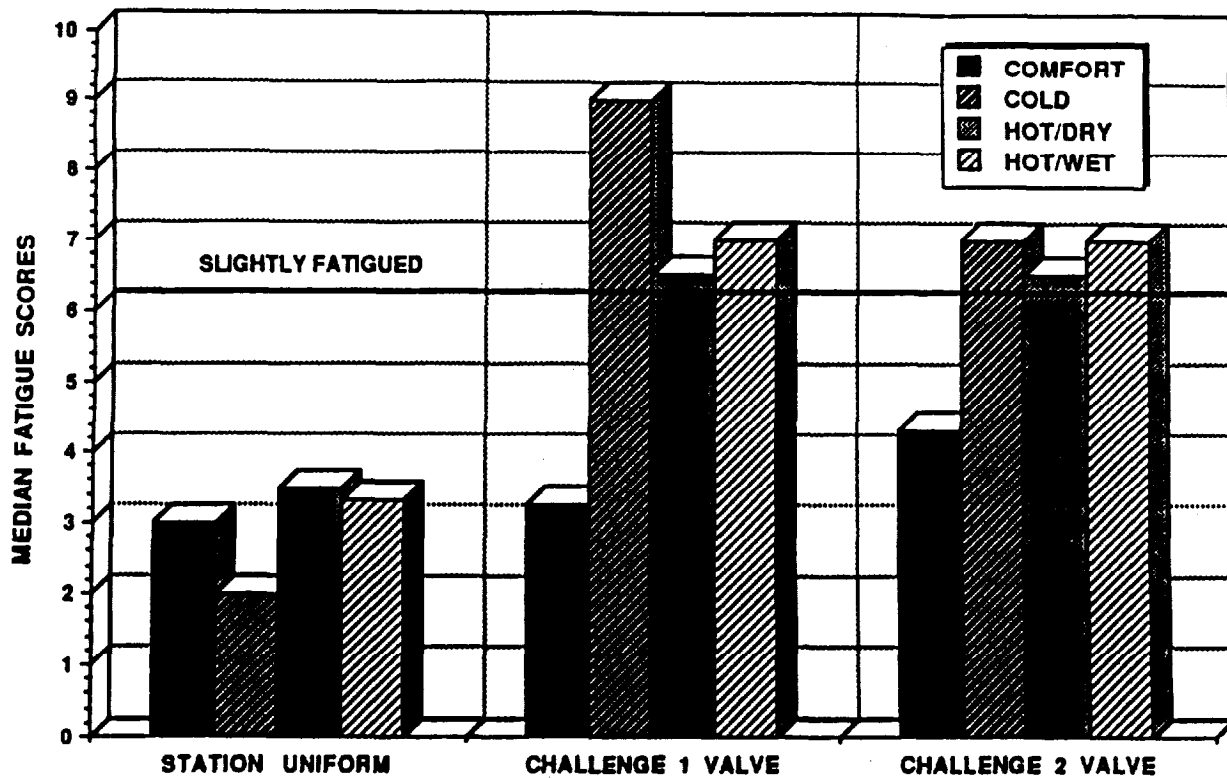


FIG.7. FATIGUE RATINGS FOR WORK/CLOTHING ENSEMBLES.

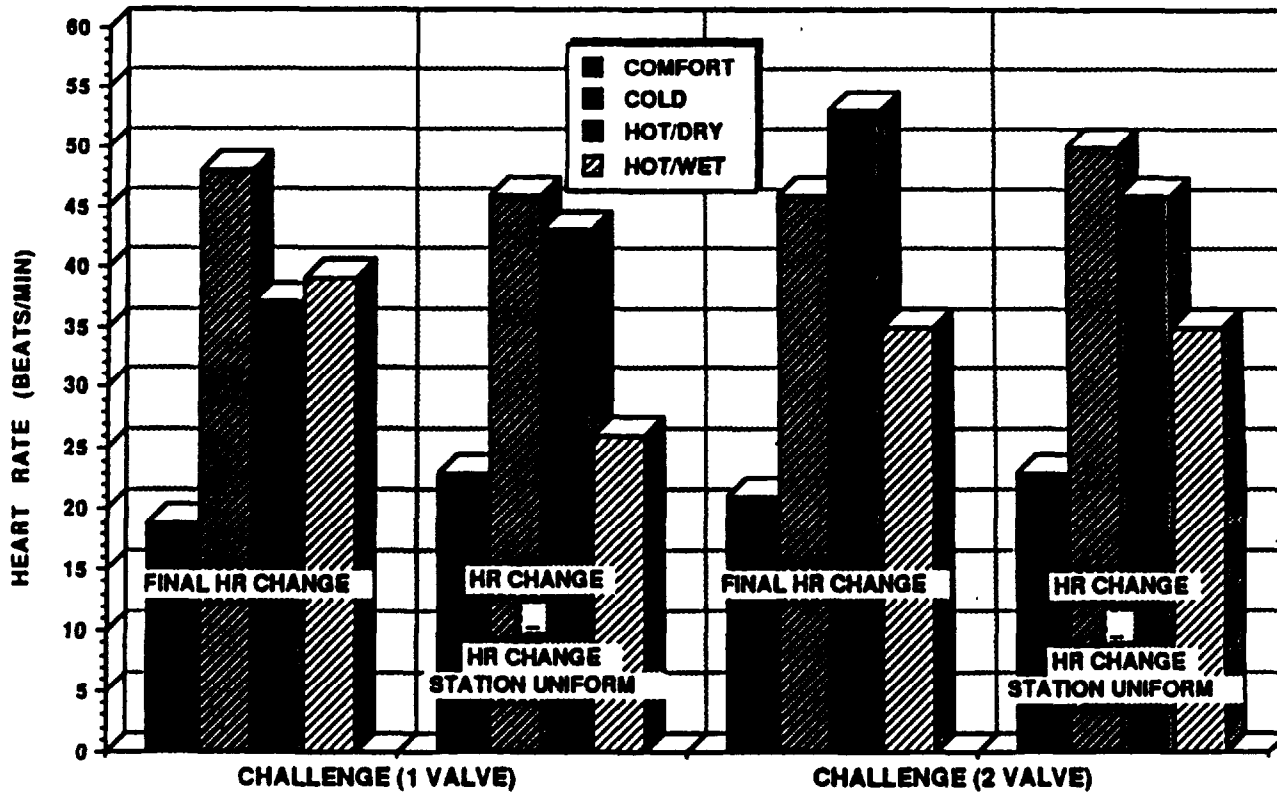


FIG.8. BURDEN OF WORKING IN CHEMICAL PROTECTIVE SUIT AND SCBA ON HEART RATE.

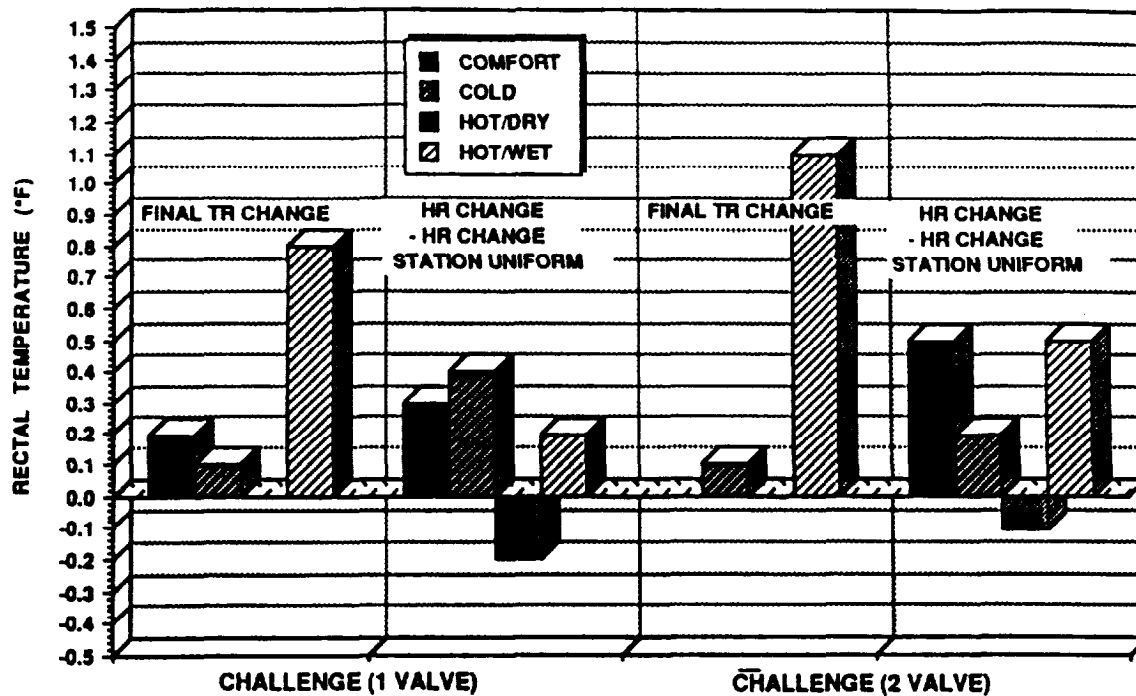


FIG.9. BURDEN OF WORKING IN CHEMICAL PROTECTIVE SUIT AND SCBA ON RECTAL TEMPERATRE.

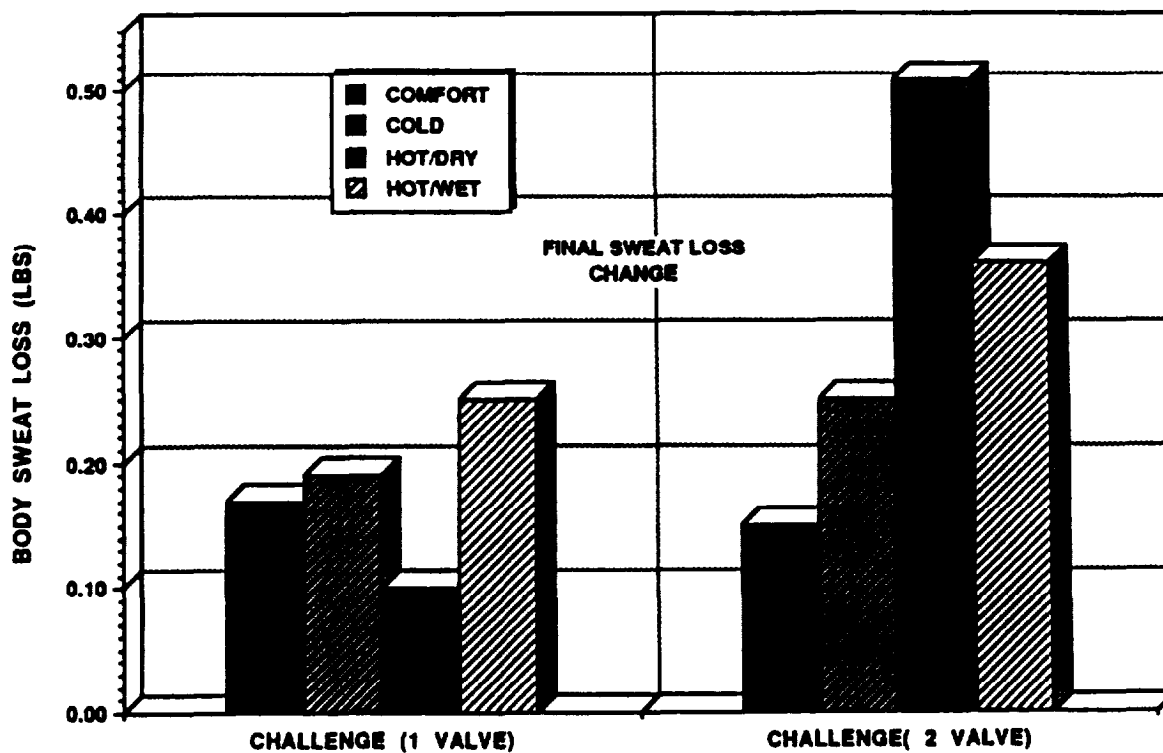


FIG. 10 BURDEN OF WORKING IN CHEMICAL PROTECTIVE SUIT AND SCBA ON SWEAT LOSS.

Figure 8 shows the effect of wearing the chemical protective clothing and SCBA on the heart rate. These values were obtained by subtracting the final or HR change from those HR values obtained while wearing the chemical protective clothing. For example, the bar in the extreme left portion of the graph labeled Final HR Change, the HR values were obtained by subtracting Chall average HR value (139) comfort conditions in Table 3 from the station uniform average HR value (120). Therefore, the difference is +19 and the higher HR is the result of wearing the protective clothing above that due to the work and climatic conditions. Figure 9 and 10 show data obtained in a similar fashion for rectal temperatures and sweat loss.

DISCUSSION

One of the major findings of this study was that the ASTM F-1154 work procedures A and B together are not strenuous enough or are sufficiently long enough to strain the fire fighter so that the chemical protective clothing can be adequately assessed.

Another finding was that any differences between the one or two exhaust valve Challenge clothing was not detectable in the assessment of the physiological parameters. Therefore, after testing both suits in field sites under comfort and cold conditions, the suits were used indiscriminately during testing under hot/dry and hot/wet conditions.

PHYSIOLOGICAL FACTORS

Heart Figures: 2A and 2B show individuals heart rate response to the effect of the outside environmental conditions, the work load and the encumbrance of the chemical protective clothing (CPC). While dressed in the protective clothing, individual final absolute heart rates varied from 111 to 171 beats/min across climatic conditions. The average final heart rates varied from 139 to 152 beats/min. Surprisingly, work in the comfort and hot/dry environments resulted in lower HR's when compared to those seen after cold and hot/wet exposures. This pattern is reflected in Fig. 2B when changes in HR above control rates are calculated. Heart rate level wearing only the station uniform clothing and no SCBA resulted in average HR of 120 beats/min or less. The average time to complete all the required work tasks was only 14 mins; this short work cycle resulted in these lower HR's. In the previous study, the task duration was 45 mins (Veghte and Annis, 1988a) with resulting higher final HR's. Fig 2C averages the HR data showing the comparison of absolute HR and change in HR responses to climatic conditions. Taking the analyses one step further, Fig. 8 looks at the effect of only the chemical protective clothing and SCBA on HR as the HR values seen while wearing the station uniform are subtracted from those resulting from wearing the clothing. In this figure, HR's were surprisingly similar across climatic conditions with the responses in the cold and hot/dry exposures generally higher than those resulting from the comfort and hot/wet conditions.

Body Core Temperatures: The rectal or core temperature (TR) of the body is one of the most meaningful physiological parameters reflecting strain on the body as a result of work, the microenvironment and clothing worn. Figures 3 A-D assess the final absolute TR or TR change of fire fighters working in various climatic conditions. Individual TR values are graphed in Figs. 3A and B while averaged values are shown in Figs. 3C and D. Again, only slight differences are seen between the two types of Challenge clothing. Absolute values were generally below 100.0°F with the highest absolute average TR measured at 100.4°F during the hot/wet suited exposures. When the data is nulled in Fig. 3D, the highest core temperature rise occurs during work in the cold and hot/wet conditions. This cold response may reflect a higher metabolic rate or mild shivering. When the station uniform TR value is subtracted, the protective clothing values in Fig. 9 show the greatest final TR rise occurs during the hot/wet exposures. This response is not

seen when TR change is analyzed. It must be remembered however that changes of a few tenths of a degree F in core temperature is probably not meaningful.

Sweat Loss: The individual body sweat loss of fire fighters is shown in Figure 4. Less than a pound of water was lost during any exposure. As expected, the largest amounts of body water loss occurs during the hot/dry and hot/wet exposures. When only the protective clothing effect is examined in Fig. 10, wearing the Challenge 2 exhaust valve suit resulted in more sweat production than while wearing the 1 valve suit. This may result in enhanced venting of the moisture laden air from the two exhaust valves so that no "clamping" of sweating occurs as might be expected with a totally wetted skin while wearing the one valve suit.

CLOTHING

Moisture in Clothing: Figure 5 shows the sweat retained by various items of clothing worn under the suit during the various climatic exposures. Most moisture is retained in the T-shirt and station pant or coverall. Even in the cold, a given quantity of water (called insensible perspiration) is lost through the skin. This loss amounts to 0.11 lbs/hour. Also while wearing the protective garments, the exhausted moisture saturated air from the lungs is dumped into the suit and some is absorbed by the clothing while the rest is exhausted. The amount exhausted in this case can be roughly calculated. For example, of the total sweat produced (hot/dry-CHAL 2) (0.86 lbs), 0.46 lbs was absorbed by the clothing (Table 10) and the rest evaporated through the exhaust valves. Therefore, the evaporative/sweat ratio can be calculated as 53% of the sweat produced.

Clothing Temperatures: Two temperatures were recorded inside the Challenge protective ensemble above and below the visor. These inside surface temperatures of the Challenge fabric were averaged and plotted in Fig. 6. These temperatures reflect an equilibrium between the outside environmental conditions and the amount of heat lost by the fire fighter. For example, the ambient conditions during the hot/dry exposures while wearing the CHAL 2 valve suit was a temperature of 97.8°F and the globe temperature (heat from the sun) is 118.9°F. The measured inside suit temperature was 102.8°F (Table 11). Therefore the suit's temperature is above ambient (97.8°F) since it absorbs infrared heat from the sun but does not reach the globe temperature as the garment's inner surface loses heat to the cooler underlying clothing and some evaporative cooling occurs. This dynamic heat balance is further complicated by the heat lost through absorption by the water vapor under the suit, a portion of which is exhausted out of the suit. The inner surface temperatures of the station uniform were measured on the front pectoral and the back scapular regions.

DESIGN CONSIDERATIONS

Anthropometry: In order to determine the body dimensions of fire fighters, a series of 20 measurements were taken on each fire fighter. The measurement procedures have been described previously (Annis et al, 1987; and Veghte, 1985). Fire fighters were measured while dressed in station uniforms. The individual data are tabulated on forms in Appendix B. The means for each measurement were calculated for the 20 subjects are presented in Table 18. Data previously collected on fire fighters are presented in Table 19 with comparable large anthropometric databases maintained by Anthropology Research Project (ARP) (Veghte, 1988a). A new large database labeled Army has been added to the original figure by ARP.

Reach and Body Motion: Body flexibility is critical to the ability of fire fighters to perform effectively. In order to examine the effect of the chemical protective clothing on body mobility, a series of functional reach and simple/complex joint motions were measured on each fire fighter (Veghte, 1985). Each person was first measured in station

uniform to establish control baseline values for each movement. The ten movements associated with joint range of movements were measured either with an anthropometer or Leighton flexometer (Leighton, 1955). The suited measurements were performed while the subjects were wearing an SCBA and the garments were inflated. The control and clothed differences in reach distance for each fire fighter wearing the Challenge protective clothing are presented in Tables 16 and 17. The overhead reach was restricted by the protective clothing with the two hand overhead reach more restrictive than the one hand overhead reach. The most severe reduction in reach was 5.6 inches in one person. Not measured is the energy required to "fight" the inflated clothing to perform this and other movements. Table 17 lists the changes in five body movements. The weight of the SCBA and inflation of the suit particularly affected torso motions.

Fire Fighters' Comments: The following subjective comments are representative of those reported on the test questionnaires after each test.

Challenge Protective Suit: The major problems with the Challenge clothing continues to be ballooning of the suit. This inflation restricted mobility, downward and upward vision. The suit inflation also made it difficult to work overhead, crawl and climb ladders. Also, several fire fighters reported that during forward bending the face shield pushed against the SCBA facemask exhalation valve making it difficult to exhale. Also, a fire fighter said his face mask seal was broken by the head part of the suit pushing against it. Another fire fighter reported that in a gusty wind situation, the wind resistance of the ballooned suit make it difficult to move against it.

A general comment was made by fire fighters that the two exhaust valve suit configuration expelled air faster when bending which resulted in better mobility than the one valve suit. The visor continues to fog up especially during cold temperatures. In fact during below freezing temperatures, frost occurred on the visor.

Other problems that surfaced was that the valve covers ripped off the suit when the suit was picked up by the cover. In one case, the ripping removed the teflon coating of the substrate material. In the other cases, it appears a delamination of the adhesive occurred. Another serious problem was the Silver Shield inner gloves. Almost all gloves ripped when the fingers were extended into them. They ripped at the seam or the tips of the fingers poked right through the material. Part of this problem was the difficulty of inserting the fingers into the Silver Shield gloves with the overglove in place. Also, there was concern regarding the lack of access to the air bottle valves or viewing the pressure gauge..

Work Load: The general comment by all fire fighters that the work load was too easy and not representative of the work load associated with most HAZMAT situations. Their assessment of the work load varied from light to moderate.

RECOMMENDATIONS/CONCLUSIONS

1. The ASTM-F-1154 work load assessment tasks and duration of these tasks are not strenuous enough or long enough to adequately evaluate chemical protective garments. This is true even if all the tasks in Procedures A and B are performed sequentially.
2. The work load associated with these work tasks was not adequate to provide a realistic strain on the fire fighters. Therefore, the measured physiologic parameters reflect only nominal strain.

3. The second generation Challenge protective garment still contain design problems resulting in excessive suit ballooning that inhibited upward or downward vision, difficulty in working overhead, crawling or climbing ladders and the visor hitting the SCBA facemask breaking its seal

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